THE UNITED STATES AIR FORCE SMALL BUSINESS INNOVATION RESEARCH PROGRAM

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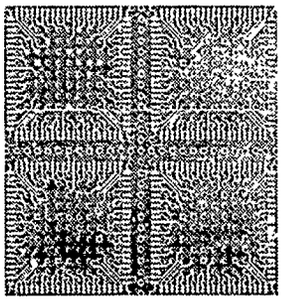
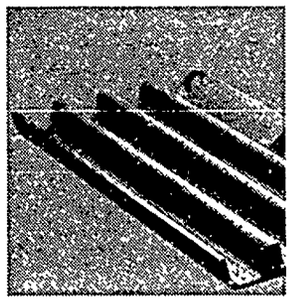
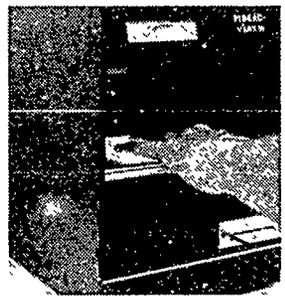
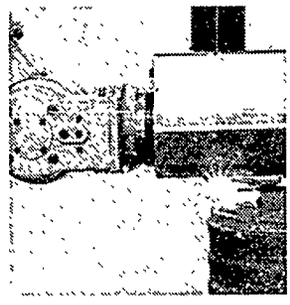





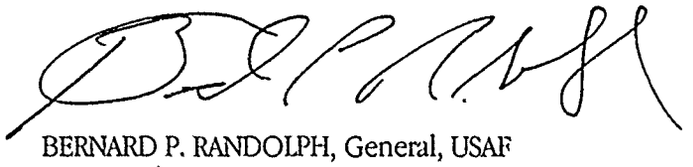
Preface

The Air Force Small Business Innovation Research (SBIR) Program began in 1983 in compliance with the Public Law 97-219, the Small Business Innovation Development Act of 1982. In enacting this law the intent of Congress was to achieve four objectives:

- Stimulate technological innovation;
- Use small businesses to meet federal Research and Development (R&D) needs;
- Increase private sector commercialization of innovations derived from federal R&D; and
- Foster and encourage participation by minority and disadvantaged persons in technological innovation.

Air Force Systems Command manages the SBIR program for the Air Force. Our SBIR Program has become increasingly effective in meeting these objectives and has become an important and integral part of the Air Force Research and Development Program. SBIR contractors are offering new technologies and practical solutions to Air Force problems.

This publication details the progress made by the Air Force in implementing the SBIR Program. It also spells out the successes and accomplishments achieved by the Air Force SBIR contractors, demonstrating that small businesses are performing quality R&D in response to Air Force needs.



BERNARD P. RANDOLPH, General, USAF
Commander, Air Force Systems Command

Executive Summary

In 1983, the United States Air Force initiated the Small Business Innovation Research (SBIR) program in response to PL 97-219. Its purpose was to stimulate research and development (R&D) among small private sector businesses while providing the Air Force and the U.S. taxpayer with innovative, cost-effective techniques and technologies.

The SBIR program has since emerged as a vital and integral part of the Air Force's overall R&D efforts. It has enabled the Air Force to investigate new high risk, innovative ideas and expedite the accomplishment of Air Force R&D goals and objectives. Under the SBIR Program, the Air Force and the private sector share the responsibility for risk, management, technology, and market fluctuations.

The United States public has benefited from the SBIR program through efficient use of tax dollars. The Air Force has augmented the small business private sector's ability to expeditiously meet R&D needs, as well as introduce new commercial technologies and products. By sharing the risks as well as the benefits, the United States Air Force is able to promote research that is on the cutting edge of a variety of technologies.

Between 1983 and 1987, some 6,630 proposals were received by the Air Force. From these, 1,045 Phase I (concept feasibility) and 480 Phase II (principal R&D) contracts were awarded. These contracts were primarily in the areas of aeronautics, space, and ballistic missiles. A total of $186 million was awarded to 856 small businesses to explore such projects as impulse radar technology, radiation-hard fiber optics, and computer-aided three-dimensional packaging.

The Air Force SBIR Accomplishments Book includes the following sections:

PROGRAM BACKGROUND—Summarizes the Air Force SBIR Program by providing a brief description of its implementation. It also describes the creation of research topics for SBIR contract solicitations and the technical management of SBIR projects. The chapter highlights some noteworthy projects that support Air Force missions and/or are strong contenders for commercialization. Judgements of Air Force officials concerning the quality of research performed in SBIR and the program's impact on Air Force R&D are also presented.

IMPACT ANALYSIS—Presents information about the effects that the SBIR program has had on participating companies. This information is derived from the results of questionnaires sent to all companies awarded SBIR contracts from 1983-1986, comparison of subsets of responses, and interpretations of data from other available sources, including the project summaries.

NOTEWORTHY PROJECTS—Highlights completed Phase II contracts selected due to their significant technological contributions. Included are noteworthy Phase II projects which demonstrate technical innovation, high return-on-investment, and/or commercialization of a project; thereby meeting or exceeding the intent of the Small Business Innovation Research Act.

ABSTRACTS—Contains results of completed Phase II contracts, summarizing the nature and scope of the project and the work accomplished. These abstracts are organized by technical area.

The index provided at the back of this publication lists these projects alphabetically by contract title and company name. In the event that additional information is required, the name and phone number of the responsible contractor is included with each project.

Summary of Air Force SBIR Program

"We find it good business to do business with small business."

Caspar W. Weinberger
Secretary of Defense
January 29, 1982

The Air Force SBIR Program is designed to encourage participation by small business in government R&D. This program was developed in 1983 in response to P.L. 97-219, which requires government agencies with extramural R&D budgets in excess of $100 million to establish such a program. The statutory percentage of contracted R&D budget set aside began at 0.1% in FY 83 and now is set at 1.25% through FY 1993.

The SBIR program office, under the Deputy Chief of Staff, oversees implementation of this program. The program office is responsible for directing Air Force field divisions and laboratories, distributing funds, reporting contract results, and establishing a liaison with the small business community, state, and federal groups. The SBIR program manager is Jill Dickman.

The program is implemented by Air Force Systems Command through the:

- Munitions Systems Division
- Wright Research Development Center
- Ballistic Systems Division
- Human Systems Division
- Rome Air Development Center
- Air Force Office of Scientific Research
- Arnold Engineering Development Center
- Air Force Engineering Services Center
- Air Force Space Technology Center

These installations are responsible for identifying solicitation research topics, selecting proposals for award, and providing project management.

The SBIR Program consists of three phases:

Phase I Contract—Feasibility of Proposed Concept

Proposals are submitted in response to an annual solicitation listing various research topics of interest to the Air Force. These proposals describe the desired/targeted results, the approach the project will pursue, and the methods by which the feasibility of such a project can be ascertained.

Phase I contracts are awarded for a six-month period and normally valued up to $50,000. These contracts are awarded to determine the following:

- If the proposing firm is capable of conducting high-quality R&D;
- The scientific and technical feasibility of the proposed concept; and
- Whether Phase I progress justifies a larger Air Force investment in Phase II.

Phase II Contract—Principal R&D

Firms completing a Phase I project are eligible to submit Phase II proposals to develop the proposed concept. Phase II contracts are awarded to conduct principal R&D and develop a prototype product, if necessary. Contracts are awarded on Phase I results and the scientific and technical feasibility of the Phase II proposal. Phase II contracts are usually awarded for a period of two years, with a value normally up to $500,000.

Phase III—Continue R&D to Production

When warranted, private sector, non-federal funds are expected to be used to pursue commercial applications of the R&D conducted in Phases I and II and to complete any further development necessary for production. Although Phase III does not include SBIR funding, it may be supported by non-SBIR funded R&D or production contracts with a federal agency for products and processes intended for use by the U.S. Government.

SBIR companies can include sole proprietorships, joint ventures, limited partnerships, associations, or cooperatives if they qualify as a small business. Eligible firms may form partnerships with universities or other non-profit organizations, provided the small business serves as the prime contractor.

SBIR participants must also meet the following requirements:

- Have, including its affiliates, no more than 500 employees;
- Be for profit, independently owned and operated, not dominant in the proposed field of operation, and maintain principal places of business in the U.S., its districts, territories, or possessions;
- Be at least 51% owned by U.S. citizens, or if publicly owned, at least 51% of voting stock must be owned by U.S. citizens or lawfully admitted permanent resident aliens;
- Principal investigators must be employed primarily by the small business. Specifically, the investigator must spend more than half of his or her time employed by the small business at the time of award and during the conduct of the effort;
- In Phase I, a minimum of two-thirds of the research must be performed by the proposing firm,
- In Phase II, at least one-half of the effort must be performed by the proposing firm; and
- Phase I and II work must be carried out in the U.S., its districts, territories, or possessions.

Many companies, including a significant number of female and minority owned firms, have developed products and processes in response to Air Force SBIR solicitations. Fifty one contracts have been awarded to female owned firms, and 181 have been awarded to minority owned firms. The resulting technology has benefited the Air Force, other government agencies, and private sector businesses.

- One successful application of an SBIR solicitation involves a technology that improves the transmission of infrared light signals from optics to an image detector. In answer to this solicitation, a firm developed the "Coherent Infrared Fiber Optic Image Bundle", which would allow these signals to transmit through a 2 meter coherent, fiber optic bundle made from heavy metal fluoride glass.

  Ancillary uses of this technology soon became evident. Remotely located sensors could transmit to centrally located detectors, which proved useful in industrial process control, robotics, medical diagnostics, and military IR vision systems, in addition to the primary goal of improved aircraft systems. The firm responsible is now a leading manufacturer of heavy metal fluoride gas.

- Another company answered a solicitation to develop new techniques for detecting corrosion in equipment and material. A preprototype "Dual Energy X ray Scanner" was developed, giving inspectors the ability to attain detailed information on material structures.

  Early detection of corrosion is expected to save the Air Force millions of dollars per year and better enable them to keep their systems in full combat readiness.

- A third company responded to an Air Force request to develop a combat simulation system that allows for extensive interaction between operators. The resulting system, named "TEEVAL" (Tactics and Equipment Evaluator), emerged as a low cost, reconfigurable laboratory system capable of simulating scenarios involving any combination of up to 2048 friendly or hostile players. TEEVAL is expected to offer the Air Force a less expensive, more efficient, and more thorough means of evaluating the performance of personnel and equipment in the future.

The Air Force SBIR program has given these and many more innovative, beneficial technologies the opportunity to be developed, implemented, and utilized throughout the United States. Small business research continues to be a viable, profitable means for the Air Force to explore new frontiers and remain on the leading edge of technology.

Analysis of Program Impacts on Firms

Since its inception in 1983, the Air Force SBIR program has had a tremendous impact on small business. Contract awards have given firms the means to pursue new technologies, hire new workers, and develop new products and processes. That in turn, has enabled them to grow, prosper, and pursue additional unexplored areas related to their field of research.

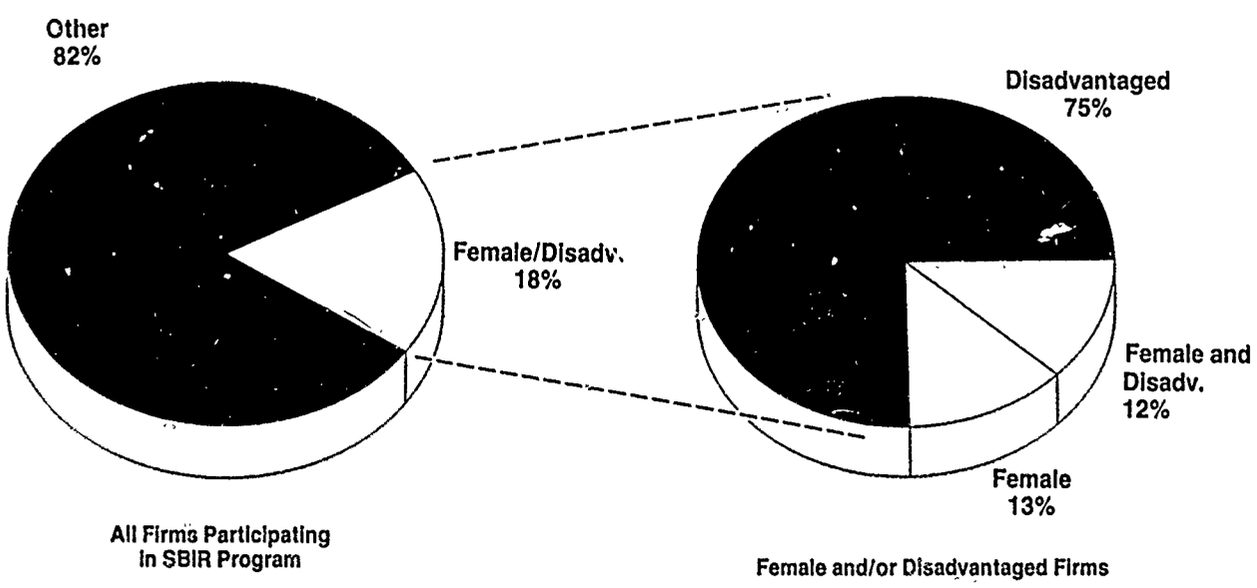
In order to track SBIR implementation, the Air Force recently surveyed businesses receiving SBIR funding and requested the following information:

- SBIR program participants
- Destination of products
- Duration of company existence
- Overall effect of SBIR funding on company operation
- Company size
- Areas of company expenditures
- Difficulties encountered during development
- Origin of non-SBIR related funding
- Nature/orientation of company business

Participation of disadvantaged firms

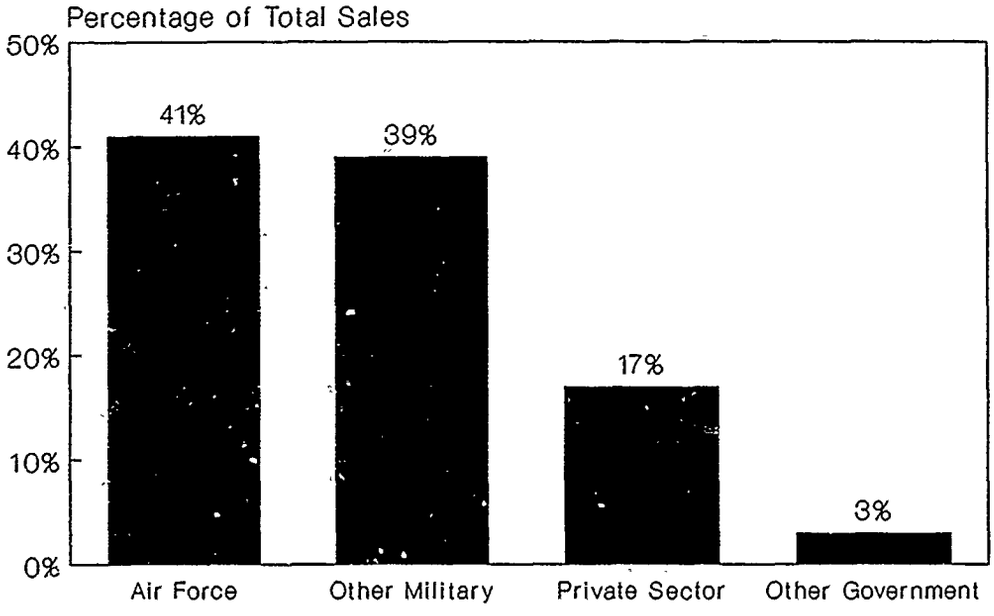
Public Law 97 219 stressed the importance of creating opportunities for disadvantaged companies to participate in research and development. The Air Force SBIR Program has been successful in meeting this objective by awarding an increasing number of contracts to female and minority owned firms, which now comprise a significant portion of all SBIR firms.

Fifty one contracts have been awarded to female-owned firms and 181 contracts have been awarded to minority owned firms between 1983 and 1987. Approximately 25% of these projects have completed Phase II, and approximately 10% have already begun commercialization in Phase III. These businesses have rewarded the Air Force by making valuable contributions in R&D. The Air Force is committed to awarding them their deserved piece of the contract pie.



Sale of products and services

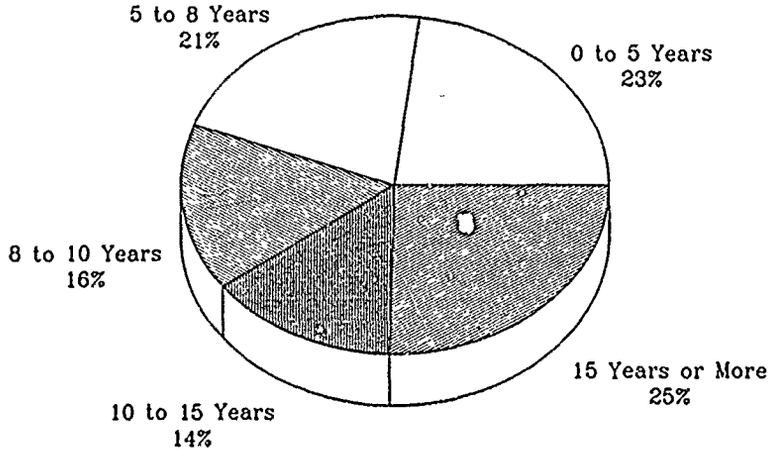
A wide variety of products and services have been developed as a result of SBIR Program funding, ranging from ballistic missile system technology to personnel training modules. The majority of these products and processes were sold to the military (80%), with the Air Force purchasing 41%. Of the remaining 20%, 17% were sold to other private sector concerns and 3% were sold to other Government entities. SBIR Program recipients anticipate that the private sector will assume a larger role in the future purchase of these items.



Recipients of SBIR Developed Products & Services

Company duration of existence

Firms receiving SBIR funding have been in existence for varying lengths of time, ranging from 93 years to 19 months. SBIR funding has enabled some newer companies to establish themselves in industry, while other companies have utilized SBIR funding to become more competitive and support on going operations.



Years in Business

Influence of SBIR funding on company success

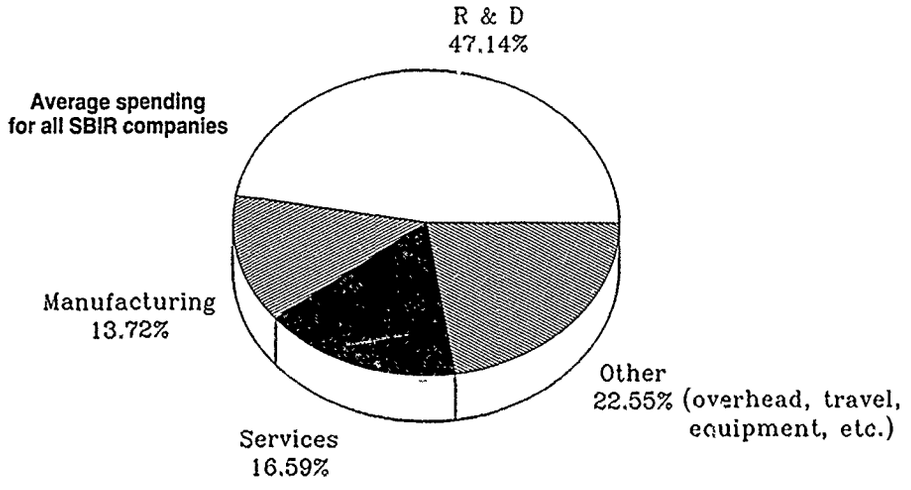
Air Force SBIR funding has been a significant factor in enabling participating companies to achieve growth and prosperity. SBIR research has helped establish firms as leaders in their particular technology, resulting in increases in production, clientele, and procurement of additional contracts. Ninety percent of participating firms attribute their success to the SBIR program.

Company size

Company size, both in terms of employees and annual revenue, differs significantly among SBIR firms. The largest graduated SBIR firm now employs 795 workers and generates over $80 million of revenue annually, while one of the smallest employs 2 workers and generates $7 thousand per year. Half of the companies employ seven or more employees and generate $325 thousand or more annually.

Company revenue expenditure

Research and Development projects comprise the most significant expenditure of SBIR companies, with the average firm devoting over 46% of its expenses to this area. Services such as administrative support, maintenance, etc. cost these companies over 16% of their budgets, while manufacturing consumes over 13% of available finances. The remainder is spent on additional considerations such as equipment, overhead, and travel.



Where Revenues are Spent

Difficulties encountered during development

While developing products and processes associated with the SBIR Program, some companies reported experiencing funding shortages, scheduling incompatibilities, technical problems, and changing markets that adversely affected their operations.

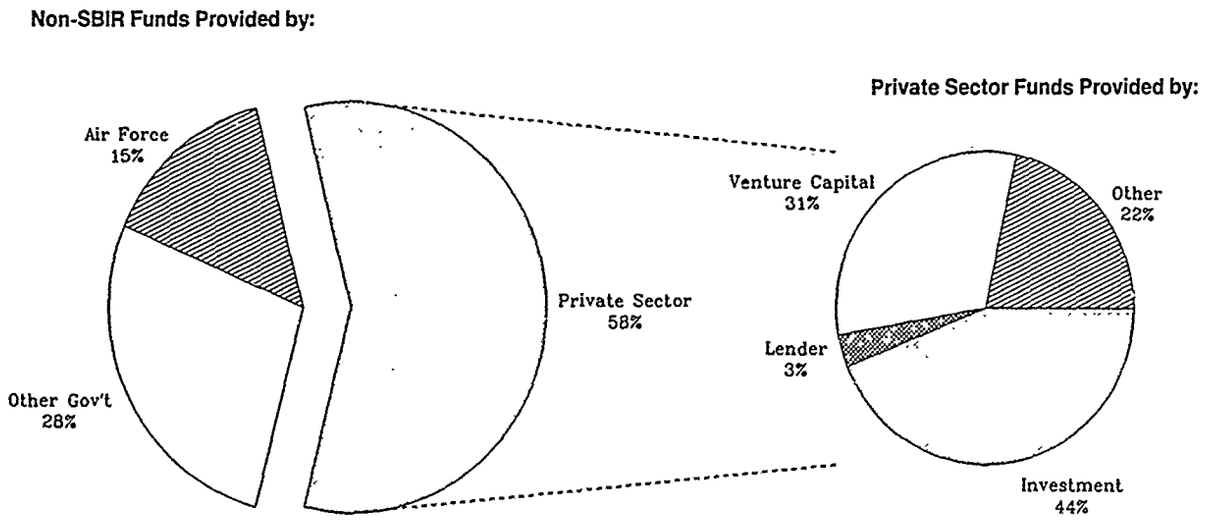
Examples of other problems included the following:

- delays in getting research material from limited sources
- companies being acquired by larger businesses
- difficulty obtaining appropriately skilled personnel
- subcontractor delivery delays

Thirty-one per cent of the companies reported no problems during development.

Non-SBIR funding

Companies involved in SBIR research also receive significant contributions from other sources, including various private sector concerns and government agencies other than the Air Force. Private sector interests comprise 57% of all non-SBIR funding, primarily in the form of investments and venture capital.



Sources of Non-SBIR Funding

Company orientation

Eighty-three percent of companies receiving SBIR Program funding are research and development-oriented The remaining firms are primarily concerned with manufacturing and computer technology. Many of these firms are active in a wide variety of disciplines, utilizing the flexibility and multiplicity of operations that make the private sector firms valuable resources for the United States Air Force.

Descriptions of Noteworthy Projects

This section describes Phase II contracts which have been selected due to their significant technological contributions. Included are Noteworthy Phase II Projects which demonstrate the following:

- technical innovation;
- high return-on-investment; and/or
- commercialization of a project.

In this way they meet or exceed the intent of the Small Business Innovation Research Act.

Additional information may be obtained by referring to the end of each article where the name of the principal investigator/company, Air Force project manager/USAF installation, and phone numbers may be obtained The index at the back of this publication lists these noteworthy projects alphabetically by contract title and company name.

The views and opinions expressed in the Noteworthy Project Section are those of the Small Business Innovation Research contractors and do not imply Air Force endorsement, factual accuracy, or opinion.

Infrared Thermography Analysis and Image Enhancement System

The development of advanced propulsion systems for future aircraft and missiles involves the thermal analysis of all components to achieve higher efficiency and reliability in engine performance. Major goals of thermal analysis are to determine the mechanism of combustion, products of combustion, and internal fluid flow patterns of combusting fluids. The majority of data obtained in these development programs is thermal information derived from thermocouples.

A thermocouple is a junction of two dissimilar metals that produce electricity by direct application of heat. The thermocouple is a single, efficient, and cost effective device when a small number of data points are required. However, when thermal information is desired over a large surface, thermocouples can reach their limitations. As the number of thermocouples increases, the number of signal conditioning and data acquisition units also increases. This dramatically increases the costs in obtaining thermal data for a large number of data points.

Another aspect of increasing the number of thermocouples is the fact that each thermocouple acts as a small heatsink, drawing away thermal energy that might not otherwise leave a surface. This may not be a significant amount of thermal loss for a few thermocouples, but for large numbers of thermocouples the loss could effect thermal processes being studied. A non-intrusive device that can obtain thermal data from visual observations is the infrared thermal image scanning system.

The primary objective of this innovative research program was to develop infrared thermal imaging processing software in conjunction with a computer workstation to fully analyze and process infrared thermal images. This innovation expands the capabilities of infrared thermal imaging devices and provides more accurate and detailed descriptions of thermal processes.

Present research of advanced combustor designs utilizes a number of complicated, delicate, and expensive techniques to analyze and acquire data. In-depth analyses of basic combustion processes are necessary to develop new designs for efficient, high performance engine combustors. Because of complicated shapes and the potentially beneficial effects of complicated mixing flow patterns inside jet engine and rocket combustors, it is impossible to accurately calculate the data on the performance of combustor designs. To optimize a combustor design requires a long series of tests during which the shape and position of internal combustor parts are varied and the results measured. A data measurement system that can adapt to the configuration changes and that can detect minor variations in internal mixing processes is required. These variations in operating characteristics are normally detected as thermal changes in combustor wall temperatures. It is desirable that a combustor wall temperature measurement system be accurate, quick, simple, and non-intrusive. Detection of radiated energy from a combustor or direct contact temperature measurement is the only available approach to this problem. Thermocouples are inexpensive and accurate, but are time consuming to install, require a large data acquisition system for a reasonable number of thermocouples, and have slow responses.

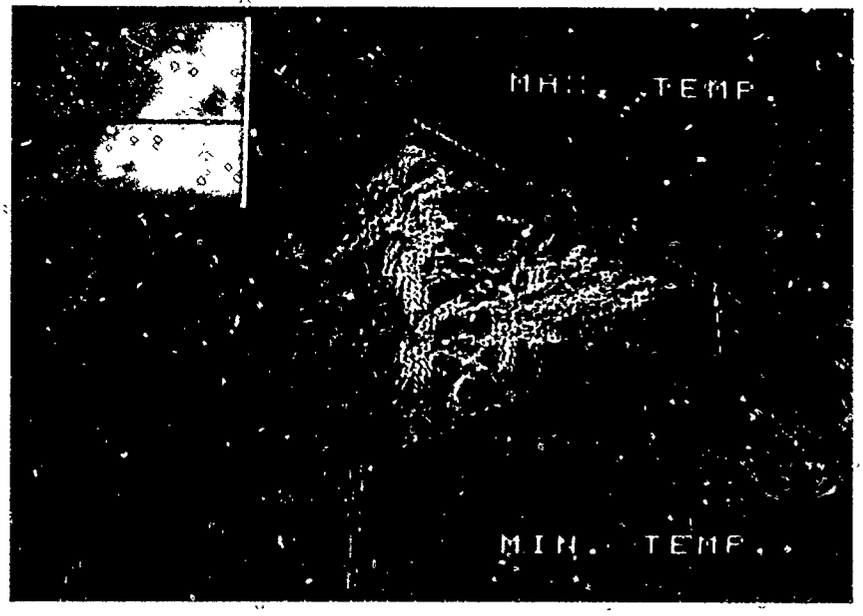


Figure 1
Three-Dimensional Plot of Infrared Window

Infrared detection equipment is a relatively new technology that is becoming more readily available for general use. It is more expensive and more complicated to prepare for operation but provides complete surface coverage, high signal response, and direct output of thermal data. It is also non-intrusive and requires no contact. The infrared thermal measurement system lends itself to the possibility of obtaining full coverage thermographic data of a test article.

The infrared viewer typically has a multi-element Indium Antimonide detector, which is electrically or gas cooled. Most infrared viewers are capable of detecting infrared radiation in the range of 2 to 5.5 micrometers. The image processing unit displays real time images generated by the infrared viewer and controls numerous display functions, such as types of display, temperature ranges, color scales, on-display thermo plots, etc.

The typical infrared image obtained from an infrared scanning camera is a plane view of the scene under observation. The image displays variations in temperature as different color bands or as different shades of gray. Thermal ranges up to 1500°C with as many as 128 thermal levels are possible. This is sufficient for most general applications where only a few specific points are of interest. However, when the thermal profiles of a surface such as a flat plate or cylinder are desired, the infrared thermal dots may not be accurate.

The infrared scanning camera utilizes infrared energy emitting from a heated object. If the point of interest on a heated object is not normal to the axis of the infrared camera, the information will not be correct. Emitted infrared radiation reaching the infrared camera is proportional to the relative angle between the normal to the surface and the axis of the infrared camera. Likewise, the infrared energy received from a cylindrical object will vary according to distance, diameter, and position. Correcting algorithms have been incorporated into the processing software to adjust for these situations. By selecting a desired area of interest and inputting a few basic parameters, the infrared data can be corrected for the angle of observation at each point in the selected window.

Figure 2
Image Processing of Video Image

Another situation in which accurate data cannot be provided is when the scene being observed contains more than one type of material. Infrared energy emitted by a heated body is directly proportional to the emissivity of the heated material. Emissivity is the ratio of emitted energy to absorbed energy from a material. Emissivity is also dependent upon the temperature of the material being heated. Most infrared scanning cameras have the capability to input only one emissivity. Software developed in this program allows emissivity to be corrected for each selected window within the scene observed. The selection of an emissivity for a material in a specific temperature range is made from an integrated data base. A large number of common engineering and high temperature materials are included. Either the software determines the proper emissivity to use or the emissivity is manually input for processing.

An infrared thermography analysis system has been developed which produces detailed three-dimensional thermal plots and line graphs of the heated surface. Figure 1 is a photograph of a thermal plot as displayed on the system's color monitor. The three dimensional thermal plot is a thermal representation of the selected window in the upper left corner of the screen. Thermal information displayed may be corrected for emissivity, circular curvature, or angular position depending upon the material being observed, shape of object (flat or cylindrical), or

the inclination relative to the infrared camera.

An added feature of the infrared analysis system is the capability to perform image enhancements of captured images. Images can be either infrared or standard video. Figure 2 is an example of an image processed to improve contrast. The left half is the original image; the right half has been processed to remove noise and improve contrast. A captured infrared image is shown in figure 3. The right half has been processed to give more detail to each thermal level and improve contrast.

This successful research effort resulted in the development of a computational data acquisition system to analyze infrared images. Infrared video images can be processed to yield highly detailed three-dimensional thermal topographic plots of the complete surface of an object. The infrared thermographic data plots give a detailed view of surface heating patterns. The accuracy of infrared data analysis is comparable to data obtained from general use high temperature thermocouples, but the infrared detection system has a much faster response time than standard thermocouples. The faster response gives more detailed thermal information of areas where thermal variations take place. Infrared data can be obtained for the complete outer surface of the test article during a single test run without contact.

Computer software, developed for processing the infrared thermal data, reduces the video information to two- or three-dimensional data plots quickly and easily. Processed information gives a unique visual perspective to observation and measurement of combustion chamber heating patterns. A completely developed and refined infrared thermal analysis workstation package with these demonstrated capabilities is certainly applicable to both government and commercial research and development programs.

This research was performed by Gary D. Streby of Universal Energy Systems, Inc., (513) 426-6900. The contract was administered by Richard B. Neff, Wright Research Development Center/POPT at Wright-Patterson AFB; (513) 255-1234. ■

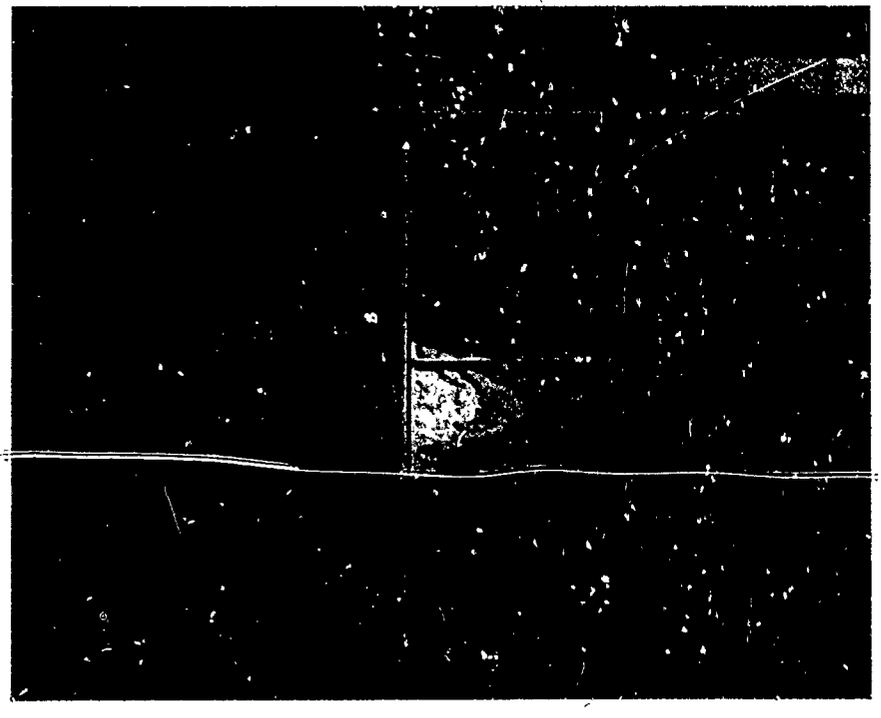


Figure 3
Infrared Image Processed to Enhance Edges and Contrast

High Temperature Oxidation-Resistant Materials for Satellite Applications

The performance of satellite rocket engines is considerably limited by currently available materials. Operations of spacecraft engines and thrusters at increased temperatures reduce propellant requirements. Since the bulk of a satellite's mass consists of the propellant needed for orbit insertion and altitude control, any improvements in engine efficiency increase the allowable payload in direct proportion to propellant savings. Currently, the limit on maximum operating temperature and lifespan is 2400°F and 10 hours respectively.

This program developed the materials and processing technology to fabricate rocket engines which operate up to 4000°F for a minimum of 10 hours. This 1600°F increase in operating temperature results in near-maximum theoretical performances by making more efficient use of the propellant and thereby decreasing overall requirements. This is of significant benefit because the propellant weight-penalty greatly increases launch costs. Also, the eventual depletion of the propellant is the primary limiting factor on a satellite's operational lifespan.

Thrust chamber materials able to withstand higher temperatures can provide important economic gains for a space mission. Rhenium, an exotic metal, was recognized as an excellent candidate. It has a very high melting temperature (5760°F), outstanding high temperature strength (surpassing that of all other elements and almost all alloys), and can be fabricated to net shape by chemical vapor deposition (CVD). Rhenium, however, oxidizes rapidly and must be protected from oxidation if the optimal combustion conditions are to be attained. An extremely suitable coating material exists in the metal iridium, which is ductile and pore free. Iridium bonds to, but does not react with, rhenium. Its thermal expansion is very close to that of rhenium, and it is resistant to oxidation up to its melting point (4420°F). Numerous attempts since the early 1960's had failed to produce viable coatings of iridium, but this track record was reversed in this program.

Fabricating a refractory metal into the thin-shell configuration of a thrust chamber was an immense challenge. The refractory metals are typically very brittle, impossible to draw, and very difficult to machine. They also tend to be expensive, so that cutting a shape out of a billet is not cost-effective. The CVD is a process that has been used with great success in such cases. CVD is best known in the semiconductor industry as a method of fabricating integrated circuits from thin layers of exotic materials with precisely controlled composition and purity.

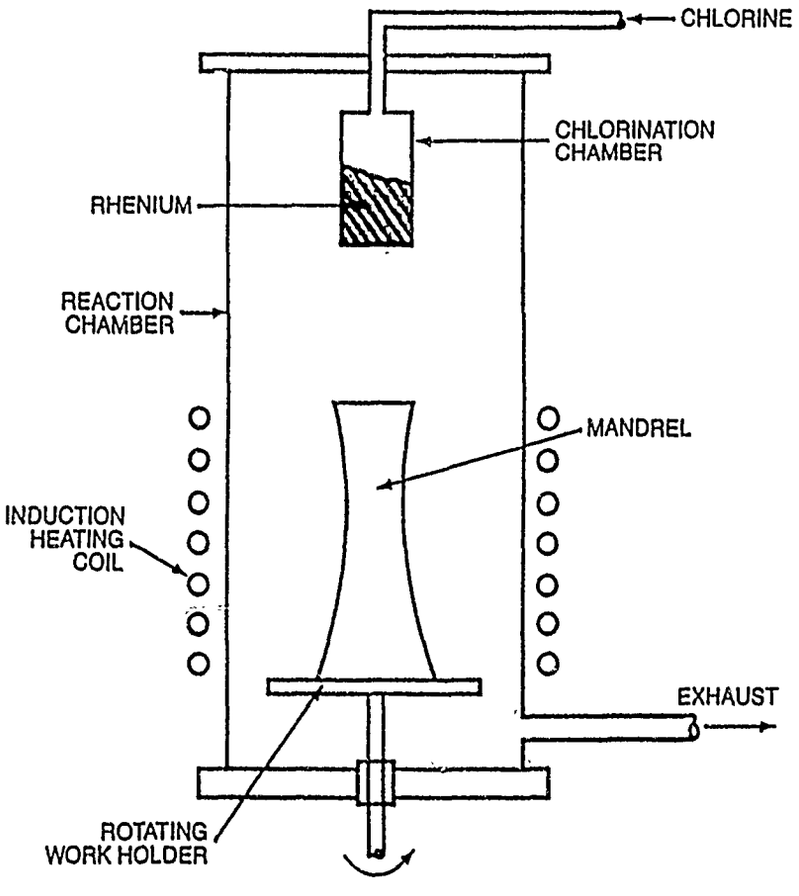


Figure 1
Schematic of CVD Apparatus for Rhenium

Another use of CVD is in the building up of thick structural layers of refractory metals and ceramics.

CVD has been studied scientifically for more than a century, but only recently has this technique left the laboratory and become a production tool. CVD is a method of plating, which relies on the chemical reaction of a vapor on a surface to form a solid structural deposit. Since this occurs on an atom-by-atom basis, impurity levels are typically less than 0.1 percent and densities are those of the bulk material. The CVD process utilizes a gaseous compound of the element to be deposited, which is passed over the heated substrate. The result is thermal decomposition or reduction of the gaseous compound, and subsequent deposition of the material onto the substrate.

In figure 1, rhenium is being deposited onto a mandrel. Chlorine gas was fed into a chamber containing rhenium metal. The rhenium was heated initially to 900°F and reacted with the chlorine to form rhenium pentachloride ($ReCl^5$). The rhenium needed only to be heated initially since the reaction was exothermic and sufficient heat was produced to sustain it. The $ReCl^5$ then passes over the mandrel, which had been heated to 2200°F by the induction coil. At the hot mandrel surface, the $ReCl^5$ decomposed, with rhenium metal depositing on the mandrel and chlorine gas passing out the exhaust. The rhenium in this form could be used as a coating or, if made sufficiently thick and the mandrel removed, could operate a free-standing structure such as a thrust chamber.

The procedure developed for depositing iridium used iridium pentanedionate as the precursor compound. This organometallic compound is also known as iridium acetylacetonate (Ir ac-ac), with the structural formula $Ir(CH_3COCOCOCH_3)_3$. The schematic of a typical CVD apparatus for depositing iridium is shown in figure 2. Ir ac-ac was heated resistively in the horizontal arm of the glass chamber. The carrier/reaction gases swept the sublimed Ir ac-ac vapor past the object to be coated, which was heated by a 450 kHz magnetic field. Iridium plated out on the object while the reaction products were exhausted.

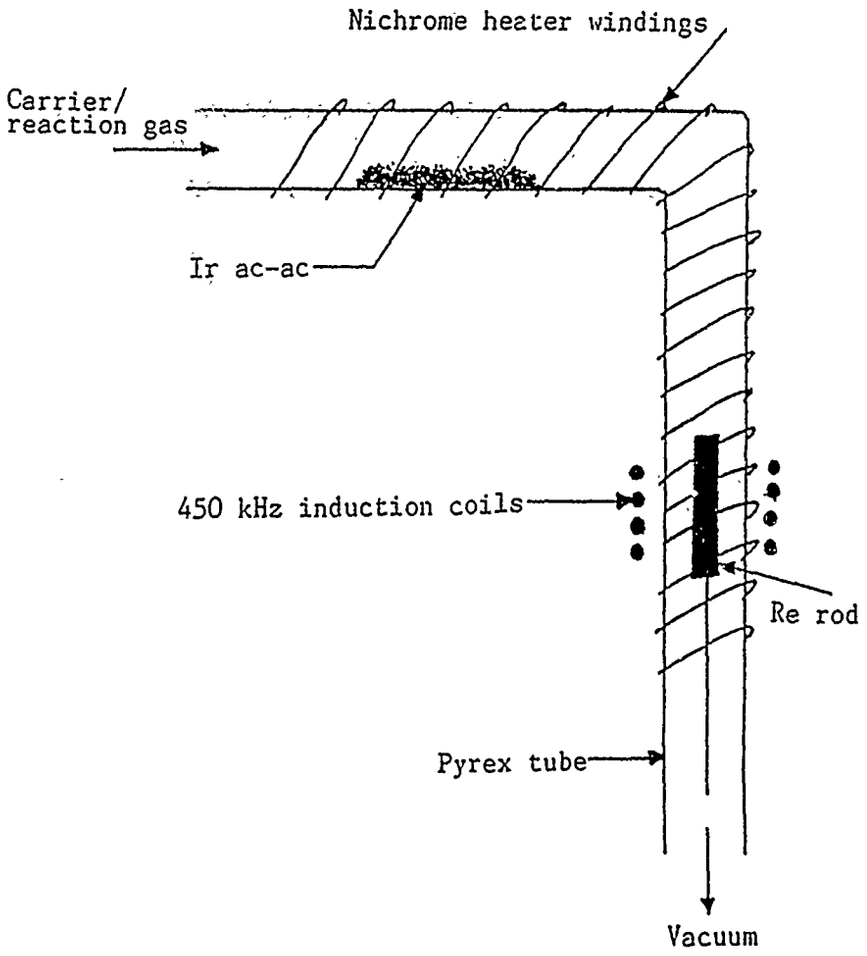


Figure 2
Schematic of CVD Apparatus for Iridium

Fabricating iridium-coated rhenium thrusters is a three-part process. The first step is to fabricate a mandrel whose surface conforms to the inside surface of the thrust chamber. The mandrel, made of a material metallurgically compatible with the thruster materials, must be dimensionally stable at process temperatures. It also must be nonreactive with the material to be deposited, have a similar thermal expansion, and be easily removed afterward. Molybdenum and graphite are often used. The second step is to deposit the iridium coating on the mandrel, typically 0.001 to 0.002 of an inch. The third step involves depositing rhenium to a thickness of 0.04 of an inch. The deposition process is modified at the final stage to leave the rhenium with a highly needle-like grained surface possessing high emissivity. This aids in the radiative cooling

of the chamber during operation. The ends of the mandrel are machined to proper length and the mandrel is chemically dissolved out, leaving a free-standing thrust chamber.

Two types of Ir/Re thrusters were fabricated. The first is a low-thrust, five-pound chamber for orbit insertion, station keeping, or altitude control. The second is a 100-pound high-performance thrust chamber designed for spacecraft trajectory corrections and orbit changes. This is an excellent candidate for the JPL Mariner Mark II spacecraft propulsion system.

Several five-pound Ir/Re thrust chambers were fabricated in Phase II. Prior to this development, oxidizer/fuel mixture ratios has been kept suboptional to avoid burn through of the rhenium. The imperviousness of iridium made it possible to raise the mixture ratio to a near-optional level, constrained only by the tankage system. Under this more oxidizing condition, the chamber temperature reaches over 4000°F. Nonetheless, one Ir/Re nozzle has survived over 4000 cycles and 15 hours of continuous operation with no measurable change in throat dimensions. None of these chambers has experienced a failure originating at the surface facing the combustion. The two experienced failures resulted from chemical attack from the outside due to the leakage of oxygen into the altitude simulation cell. This, of course, could not occur in a true space environment.

Two 100-pound Ir/Re thrust chambers were fabricated and test-fired as the program moved into Phase III. One has accumulated over four hours of firing at temperatures over 3600°F. Some blisters have appeared, but they apparently do not extend to the rhenium interface because there has been no weight loss or other sign of rhenium attack. The other unit has been hot-fired for 3000 seconds to date. Both units remain serviceable and await additional testing. Thrust chambers now are being fabricated for even more severe conditions.

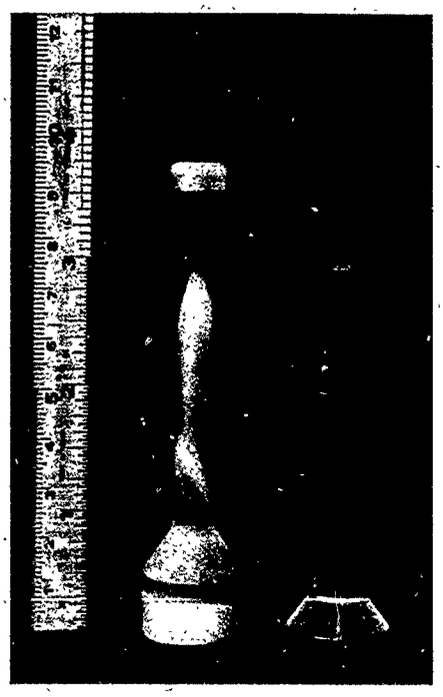


Figure 3
Thruster and Mandrel

The tests demonstrated that the rhenium/iridium structure possesses sufficient strength at 4000°F and is capable of operating at 3800-4000°F for at least 15 hours of burn time. It also confirmed the viability of this fabrication method for producing aerospace-grade hardware. Rhenium can be fabricated into a thin-shelled chamber, which can withstand the stresses encountered in a rocket engine operating at 4000°F. Iridium protects rhenium from combustion gases at 3800°-4000°F for at least 15 hours. CVD is a practical fabrication process for both iridium and rhenium in rocket engine applications.

The potential gains from this technology are enormous. Satellite lifespans can be increased by 20 percent, and the resultant cost savings per satellite have been estimated at tens of millions of dollars. Spacecraft payload capability can be increased by 30 percent, or conversely, satellite weight can be decreased by several thousand pounds. Scaling up the process for larger engines, with similar performance improvements, is clearly possible. Phase III work continues with a number of propulsion system manufacturers, satellite manufacturers, the Air Force, and NASA to capitalize on this technology breakthrough.

This research was performed by Richard B. Kaplan of Ultramet; (818) 899-0236. The contract was administered by Kurt G. Chandler, Astronautics Laboratory at Edwards AFB; (805) 275-5538. ■

Fluid-Filled Aircraft Transparencies

Present performance of windshields, canopies, and windows of Air Force aircraft must be improved as higher speed planes become operational. Specifically, better protection of pilots and other aircraft personnel, as well as sensitive cabin instrumentation, is vital. Possible threats include elevated cabin temperatures due to external air friction heating and electromagnetic pulses.

One promising solution to this problem is the addition of a circulating fluid and new protective/reflective coatings to the transparent plastic windshield, canopy, or window of the aircraft. Multiple fluid flow channels can be formed either by an appropriate modification of the plastic mold or by a direct machining process. Essential requirements of the fluid-filled transparency are high optical quality, insuring good pilot visibility, high system reliability, low added weight, good structural integrity, and adequate abrasion resistance of the external surfaces. Special optical or electro-optical materials, such as dye/pigments, also can be added to the circulating fluid for enhanced protection against incoming infrared and other optical radiation.

Results of experimental and theoretical studies have led to the conclusion that fluid flow can be well within the laminal flow regime. It also revealed that fluid flow can remove an estimated maximum continuous incoming energy load of 4.2 kilowatts. Fluid temperature rise was a modest 10°F for a relatively low total fluid flow rate of 10 liters per second. Figure 1 shows temperature profiles, or isotherms, determined for a typical 2 centimeter thick acrylic plastic transparency in the presence of fluid-containing slots. Isotherms were between 40° and 160°F, which are below the softening temperature of acrylic or polycarbonate plastic currently used in aircraft transparencies. In addition, experiments with optically absorbing dyes, pigments, and electro-optic materials demonstrated feasibility of protection against both continuous and pulsed external radiation.

Protective/reflective thin films have been sputtered with excellent adherence performance on acrylic, polycarbonate, and glass. Materials yielding best performance to date were gold on chromium for high optical reflections and silicon carbide for good abrasion resistance. Film thicknesses have negligible effect on required mechanical tolerances.

Commercial spinoff products from this project include a low cost portable fluid filled thermal blanket, an improved low cost flash protective helmet, and high-quality transparent conductive films on plastic as well as glass. The thermal blanket is capable of protecting cabins of commercial or military aircraft parked on the ground against extreme cold or hot atmospheric environment fluctuations. This proves much more effective than the common cardboard visors extensively used in parked automobiles. A lightweight blanket design allows convenient and rapid installation or removal. The protective helmet product has application in welding and other areas where better protection against high intensity infrared radiation is important. The transparent conductive film product provides lower cost with high abrasion resistance on many substrate materials, including plastics.

This research was performed by Boyd Justice of Sputtertex Corporation; (214) 869-3456. The contract was administered by Michael G. Gran, Air Force Systems Command at Wright-Patterson AFB; (513) 255-5060. ■

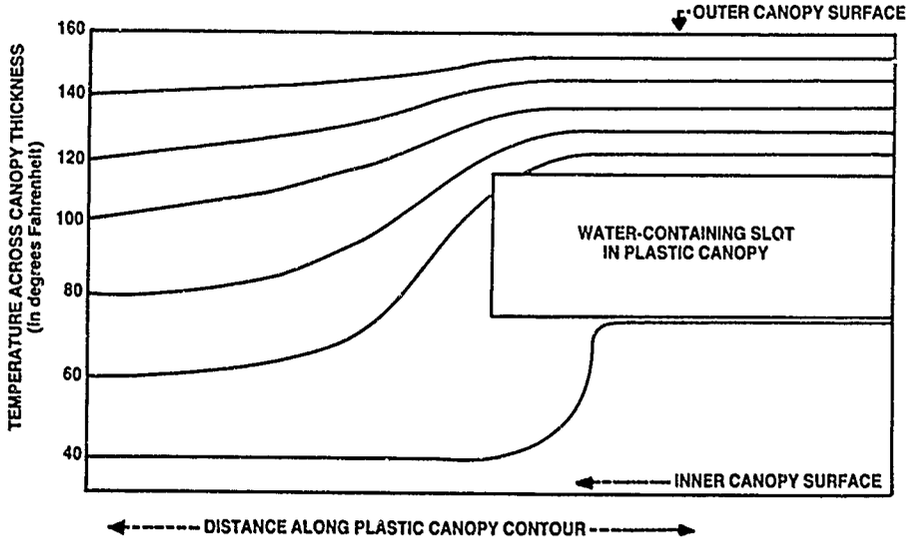
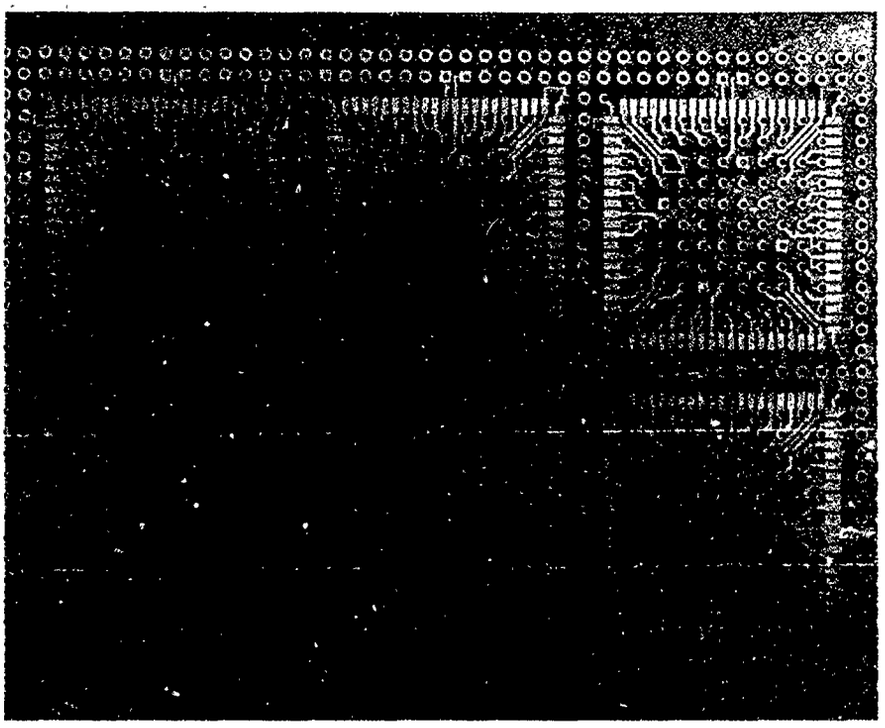


Figure 1
Temperature Profile of Fluid-Filled Acrylic Plastic Canopy

Ordered Polymer Films for Multilayer Printed Circuit Boards

Ordered polymer films made from poly benzobisthiazole (PBZT) and poly benzobisoxazole (PBO) are used as substrates for multilayer printed circuit boards and advanced interconnects to fill the current need for high-speed, high-density packaging. It is clear that very high-speed electronic circuits, using leadless chip carriers with perhaps 250 input/outputs per chip, exceed the limits of today's materials for chip-to-chip interconnection. New designs such as multilayer boards (MLBs) require thin interconnect substrates with uniform controllable coefficient of thermal expansion (CTE), excellent dielectric properties, low moisture absorption, high temperature capability, and simple reliable processing methods. Substrates, using biaxially oriented liquid crystal polymer films processed from nematic solutions, are made as thin as 0.002 of an inch. PBZT films are processed and laminated to make a substrate with dielectric constant of 2.8 at 1 MHz and a controllable CTE of 3 to 7 parts per million per degree celsius (ppm/°C).



Prototype Multilayer Circuit Board Fabricated in a Production Environment

Recently, major advances have been made in the progression of conventional dual in-line packages (DIP) to direct surface mounting (DSM). DIPs are limited in size by the large pins, which must be mounted through holes in the circuit board. DSMs can be mounted on both sides of the board and have many more smaller input/output (I/O) connections. The full benefits of increased speed and reduced size and weight have not yet been realized. This is because interconnection of DSM devices has not kept pace with I/O density. Also, the reduction in size, possible with leadless perimeter and grid array packages, has not been fully explored.

PBZT and PBO are ordered polymers, forming long rigid rod molecules. These molecules give rise to a microfibrillar network structure in biaxially oriented films as shown in figure 1. Such biaxial films have been used in combination with low dielectric constant resins, such as cyanate ester resins,

Requirements	Acceptable Levels
CTE (x-y)	3 to 7 ppm°C tailorable
CTE (z)	-17 to 18 ppm/°C
Dielectric constant	<3.5 (VHSIC <3.0)
Moisture absorption	<0.5% (saturation)
Single layer thickness	<2.5 mils
Flexural strength	> graphite/epoxy
Resin-reinforcement adhesion	> graphite/epoxy
Tg	>200°C
Processing	Compatible with existing modes

Table 1
Requirements for Surface Mount MLB

to make circuit substrates for use in MLBs as diagrammed in figure 2. Orientation of the film was used to tailor and control the CTE. The low dielectric thin film layers provide more controlled impedance and reduced crosstalk at a finer pitch than other high substrate materials.

Requirements for advanced military MLBs are shown in table 1. One of the major problems of using leadless ceramic chip carriers in advanced avionics VHSIC and VLSI applications is the mismatch between the CTE of alumina chip carriers (6.4 ppm/°C). This mismatch results in work-hardening and cracking of solder joints, which attach the devices to the substrate. Thermal cycles as extreme as -65°C to +125°C may be encountered and are known to cause solder failure and other damage. Ordered polymer films can solve this problem because they can be matched to the ceramic CTE. Moreover, ordered polymers have excellent dielectric properties.

Fiber reinforced substrates (Kelvar and graphite reinforcement) are being developed to match the ceramic CTE, but these materials have drawbacks. Fibers must be woven into a fabric, or cross-plied, resulting in increased thickness and anisotropy at a relatively large scale (fiber tow diameters are about 0.002 in., minimum fabric thickness is about 0.0045 in.). Additional problems arise from high dielectric constant and costly manufacturing. Copper-Invar-Copper (CIC) laminated foils provide matched CTE, but these materials are relatively heavy precluding their use in avionics applications and require insulation on the surface and inside vias (holes which connect multilayers). Ceramic substrates are not considered, because their brittleness and high dielectric constant (9 10) preclude their use.

Polyimide films suffer from high moisture absorption (5 percent by weight), which degrades dielectric performance and causes hygroscopic expansion. PBZT or PBO films provide a thin, homogeneous, continuous reinforcement to overcome the disadvantages of current materials. Table 2 summarizes the properties of biaxially oriented PBZT films.

During processing, rod-like molecules are formed into a microfibrillar network with homogeneity down to a very fine

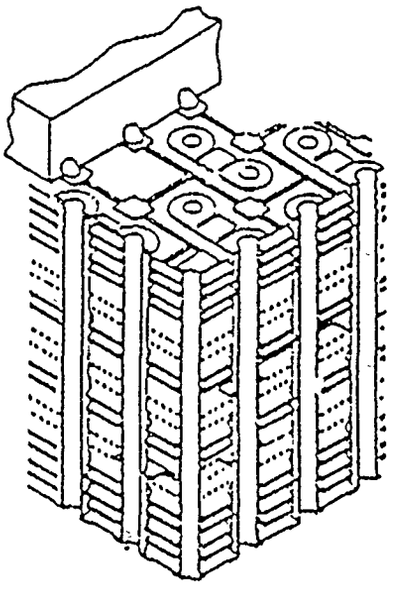


Figure 2
Multilayer Circuit Board with Surface Mounted Components

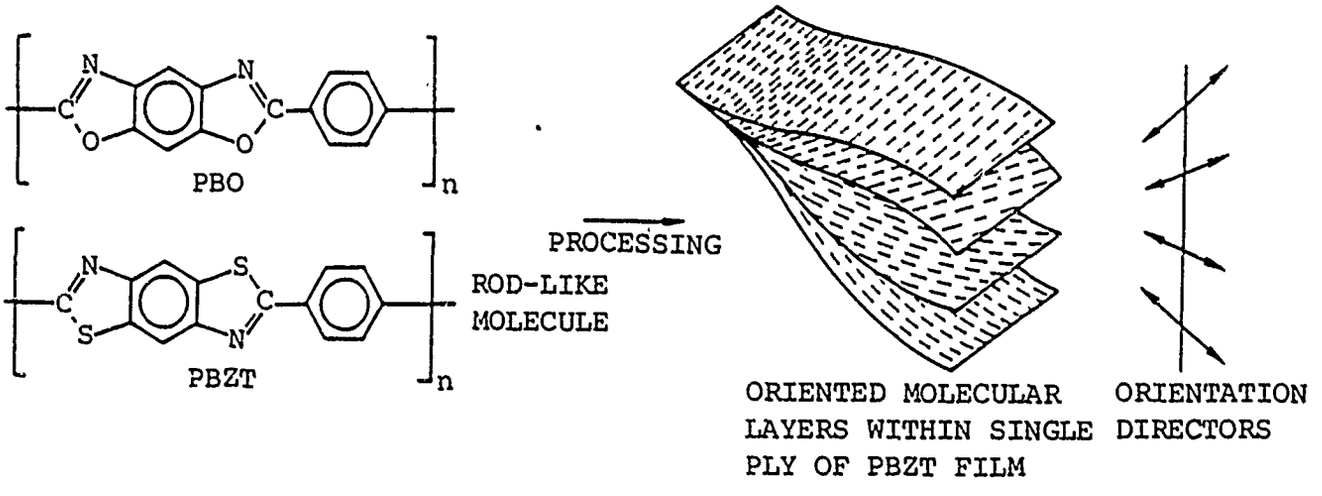


Figure 1
Microstructure of PBZT Film

scale—below 0.1μ. Thus, the self-reinforced material appears continuous to the relatively large electronic components, printed conductors, and other features of the electronic package. After processing, the mechanical properties of ordered polymer films are consistent and repeatable. The films show excellent environmental stability, including low moisture pickup (less than 0.5 percent by weight after 24 hours immersion at 25°C). The completely processed films cannot be further formed by application of heat and pressure. In fact, tests of tensile strength at 300°C indicate that the materials retain 75 percent of their room temperature properties.

The biaxial film processing techniques resulted in films with a specific, controllable molecular orientation in the plane of the film. When these oriented films are used in conjunction with a positive CTE matrix material (such as epoxy or polyimide), the net thermal expansion can be tailored to the 3 to 7 ppm/°C desired for PWB substrates. This is done by controlling film to resin ratio and cross-plying the film layers.

In summary, PBZT and PBO ordered polymer films should eventually lead to PWBs with circuit densities now common to the semiconductor industry. Advanced computer systems are dependent upon very high density circuit boards having a large number of internal planes. They also rely on many conducting circuit lines and a multitude of holes formed in close proximity to the internal conductors. Higher density PWBs are needed to meet the increasing density of circuits packaged on semiconductor devices and modules. This includes chip-on-board, multichip modules, and flexible circuitry.

Property	Value
Tensile modulus of elasticity	10 (10^6) psi
Coefficient of linear thermal expansion (in the film plane)	-7 (10^{-6}) in./in./°C
Ultimate tensile strength	80 (10^3) psi
Ultimate compressive strength	10 (10^3) psi
In-plane Poisson's ratio (estimate)	0.3
In-plane shear modulus (estimate)	0.1 (10^6) psi
Dielectric constant	2.8 to 3.2
Dissipation factor	0.002 to 0.008
Maximum use temperature	over 400°C
Moisture absorption	Less than 0.5% by weight
Film thickness	0.005 to 0.003 in.

Table 2
Properties of Biaxially Oriented PBZT Film

This research was performed by Richard Lusignea of Foster-Miller, Inc.; (617) 890-3200. The contract was administered by Herbert Schwartz, Wright Research Development Center/MLBC at Wright-Patterson AFB; (513) 255-9078. ■

CEESIM/Suppressor Implementation

Simulation systems are currently available to test individual radar, electronic warfare, and communication equipment in thousand player scenarios. Engagement models are available to evaluate missions against hundred player controlled scenarios in non-real time for analysis purposes. Large scale training exercises and one-on-several simulation facilities provide for operator participation and training. These approaches, however, are not appropriate for the evaluation of integrated systems such as manned or unmanned avionics, electronic-counter-measure (ECM), and weapons. None of these approaches represent major conflict conditions or lethal capabilities of coordinated air and ground threat scenarios. Thus, the development of sophisticated integrated avionics and weapon systems to counter the numerical superiority of the Warsaw Pact was pursued to ensure that they will work in the intended environment.

This limitation results from the methodology in which the simulation process was conducted (the definition and scheduling of scenario events prior to the simulation phase.) As a consequence, the scenario was inherently fixed during the actual simulation. By separating the scenario definition from the scenario simulation, the scenario was unresponsive during simulation to the reactions of the system or systems being evaluated. In effect, present dense scenario simulators are open loop systems and can not be used to evaluate integrated systems without a great loss in evaluation accuracy. For example, to evaluate an aircraft station, the platforms of the simulated scenario must be reactive to the instantaneous position and electronic-counter-measure (ECM) of the aircraft station. Not only must the equipment under evaluation, manned or unmanned, be responsive to the simulated scenario, but the scenario must be responsive to the equipment. Hence, a closed loop simulation system, as illustrated in figure 1, was required.

Closed loop simulation exhibited certain valuable features not possible with open loop simulation. Three key features are.

1. The scenario, and consequently the evaluation process, are always in the proper context of the actions by the equipment under evaluation. This greatly enhances the integrity of the evaluation process by testing manned and unmanned equipment with a tactically correct engagement. True man/equipment-in-the-loop operation is thus provided.
2. The autonomous behavior of equipment can be fully evaluated. This is possible since the equipment is not driven or guided by an unalterable scenario. The interactive feedback permits the observation and analysis of dynamic phenomena such as convergency and stability, which are repressed by conventional open loop evaluators.
3. Greater evaluation flexibility

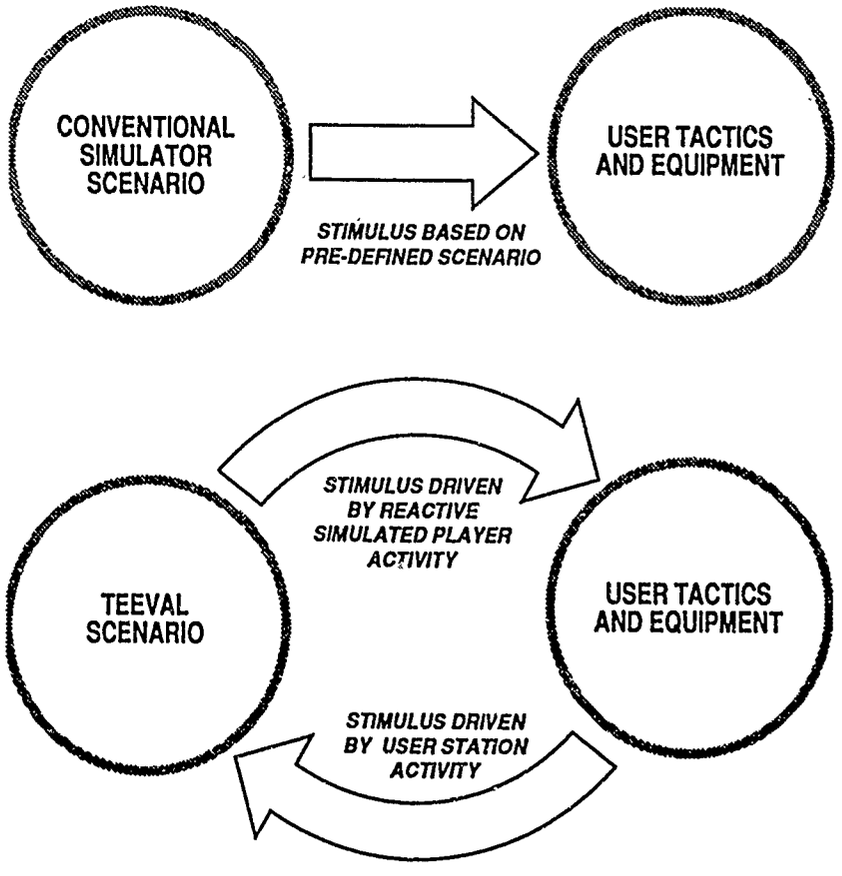


Figure 1
Conventional vs. Closed Loop Evaluation

and resolution are possible. Scenarios can be selected with outcomes that were highly dependent on equipment activity. These new scenarios permit the user to evaluate "close up" the interaction between the equipment under evaluation and its environment in a tactical situation.

The development of a closed loop laboratory simulation capability for dense combat scenario tactics and equipment evaluation was the objective of this project. The simulation system was named the Tactics and Equipment Evaluator (TEEVAL). There were several formidable technical challenges. If the density of a European battle scenario with thousands of platforms, sites, and emitters was considered, then to support target representations and men-in-the loop participation, the dynamic motion and positional attitudes of all players must be simulated in real time. For tactics evaluation, all players (simulated and actual participants) must be reactive to each other. Since action and reaction decisions were heavily dependent on sensor outputs, all sensors associated with each scenario player must be simulated. Aircraft pilots participating as players, for example, must see valid readouts and displays, have control over the motion of their aircraft in the scenario, and control of associated weapons and sensors. Finally, a detailed representation of the terrain was required to support terrain masking and target representation for terrain measuring sensors.

The functional sections of the TEEVAL concept are shown in figure 2. The Engagement Generation Unit (EGU) is a digital computer system dedicated to the real time execution of interactive models which simulate the systems and actions of each player in the scenario. The states of these players, their position, and emission and weapons firing status were calculated and updated by the EGU at a rate of 32 updates per second. As this information was generated, it was provided to the Scenario Representation Unit (SRU). The function of the SRU was to provide a stimulus for each system under test (SUT). Thus, the scenario and the status of all the players were represented. The SUT sensors were stimulated as if the scenario were real, and the SUT might then react in some fashion such as altering its movement and emission status or firing a (modeled) weapon. These actions were in turn monitored by the EGU. The interactive models in the EGU took into account the actions and states of all the SUT's when simulating player systems and actions. The EGU employed the suppressor composite mission level model in a software shell that supports real time interactive operation. The principle component of the SRU was the Combat Electromagnetic Environment Simulator (CEESIM), which provided SUT sensor stimulus with pulse-by-pulse resolution at digital and radio frequency (RF) levels.

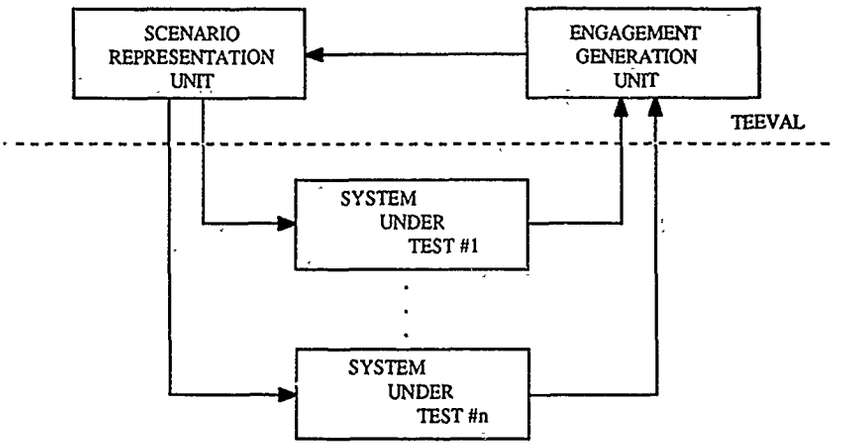


Figure 2
TEEVAL Functional Sections

Figure 3 illustrates the simulation of players and the representation of SUT in the simulated combat scenario. In the EGU, the states of all simulated and actual players were represented. These states were updated in real time at a 32 Hz rate by the player models in the case of simulated player states, or by monitoring the SUT in the case of actual player states. The integrated representation of players in the scenario was a fundamental feature of TEEVAL which supported simulated and actual player interaction.

For example, the SUT consisted of a pilot in a mock-up cockpit with a fully operational electronic warefare (EW) receiver system. The SRU stimulated the EW receiver system and created the out the window displays and radar model of the mock-up cockpit. The EGU simulated the actions of friendly and threat players and also monitored the states of the SUT, such as the position of the "aircraft" calculated by the SUT aerodynamics model and the status of the radar transmitter and

weapons system models. The simulated players were able to sense the SUT (inasmuch as their sensor capabilities permit) by using emission and calculated position information of environmental factors. The simulated players were themselves reacting to the SUT, thus providing the SUT with a reactive scenario.

A prototype TEEVAL system was demonstrated in the fall of 1986 with a mock up cockpit as the SUT. All functional sections of the TEEVAL concept, including real time suppressor operation, were represented. Individuals were able to engage TEEVAL simulated pilots/aircraft in an air combat. In the majority of cases, the superior knowledge base of the decision process models and consequent optimized simulated pilot performance proved to be the deciding factors in the outcome of the air combats. Real time suppressor control of the CEESIM was demonstrated in early 1988.

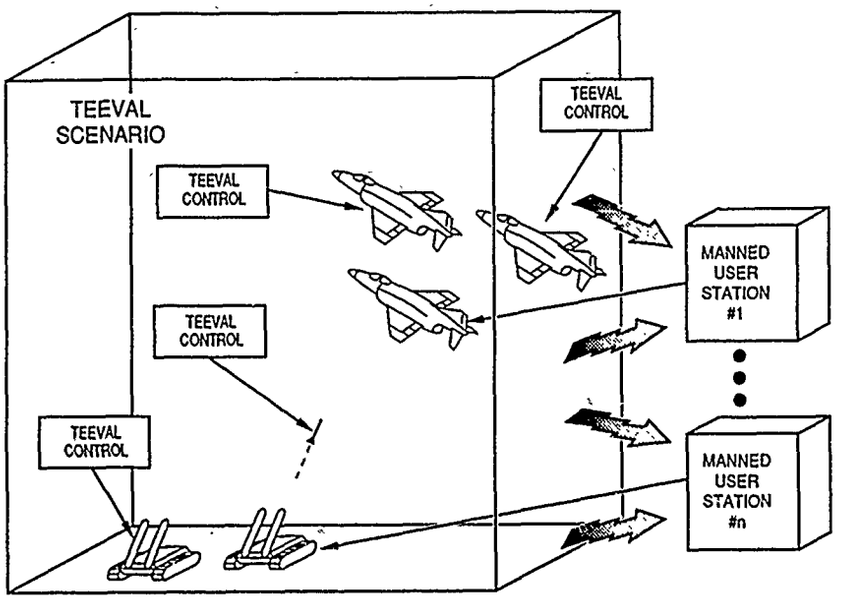


Figure 3
Representation of SUT and Simulated Players Engaged in TEEVAL Scenario

The baseline TEEVAL system was delivered to the Avionics Laboratory at Wright-Patterson Air Force Base (AFWAL) in the summer of 1988.

The TEEVAL has application to many Department of Defense programs at all levels of system development, including problem definitions, concept evaluations, and performance demonstrations. Many of these efforts are supportable by low cost digital versions of TEEVAL. More sophisticated versions of TEEVAL with RF generation, ECM signal distribution, echo pulse generation, and many men-in-the loop stations are capable of supporting detailed evaluations and provide training for a broad range of tactical engagements, such as analyses of Green Flag exercises or of the Libyan raid. Most importantly, the use of engagement models in combination with the high emitter/platform of the CEESIM will achieve the goal of systems evaluation in dense combat scenarios.

This research was performed by Cesar Bandera of Amherst Systems, Inc.; (716) 631-0610. The contract was administered by Lt. Col. Glenn Harris. Aeronautical Systems Division/RWA at Wright-Patterson AFB; (513) 255-2108. ■

Automatic Derivation of Performance Constraints and Generation of Design Guidelines

Embedded computer applications, such as signal processing, real time artificial intelligence, and image processing demand high performance beyond current capabilities. These embedded computer applications are usually severely constrained by factors such as power, weight, size, schedule, reliability objective, and cost. The Integrated Design Automation System (IDAS) focuses on solving the design and programming problems inherent in this type of system.

Embedded computer design and application problems are well suited for design automation and optimization techniques. Their computational requirements are known, so they may be characterized by specification and program benchmarks. Noncomputational requirements, such as power and cost, are also known and likewise may be explicitly noted. Valid solutions must simultaneously consider and satisfy all of the design requirements and constraints.

IDAS assists users in solving these application problems by allowing rapid evaluation of numerous designs with objective and quantitative comparison of alternative approaches. To further aid users in making design and programming decisions, the IDAS provides feedback on weaknesses and guidelines for design improvements.

Hardware designs (based on resources and machine paths used to generate microcode) were analyzed for potential bottlenecks. Software designs, entered in Ada, were analyzed for program and data structure, and variable usage. IDAS generated microcode for the Ada program based on a given target machine description. Then it reported to the software designer when unsupported software constructs appeared in algorithms. The performance of alternative software implementations could be examined for one or more hardware configurations. Differences were measured quantitatively. This relationship is more clearly shown in figure 1.

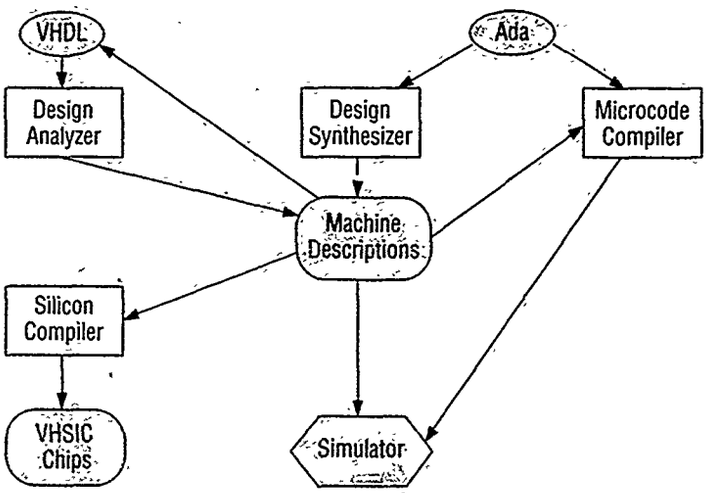


Figure 1
IDAS Top-Level Diagram

The process of generating microcode and compacting it for a horizontal processor gave the hardware designer valuable information. For example, field conflicts in the microcode word as well as resource conflicts provided important knowledge. IDAS recommended additional hardware components when appropriate. The designer could make a change in the hardware (e.g., delete an ALU, add a multiplier, or reduce the amount of power available) and directly measure the impact of that change on any program performance. Coupled with the ability to automatically retarget the environment came the ability to evaluate numerous alternatives and to perform cost/benefit tradeoffs.

Primary objectives of the design process were to synthesize a machine that was well suited to execute specific key algorithms and to structure an algorithm whose execution worked on a particular machine architecture. The IDAS is instrumental in providing information for design improvement, so that system designers can constantly strive for high quality solutions.

Within the IDAS there are numerous software elements that perform analyses and optimizations. These software elements optimize the mapping of an algorithm onto a target machine architecture. They derive information about the relationship

between algorithms and the machine, and discover the reasons if an optimum mapping cannot be achieved. This information consists of such things as data path, control field, and resource conflicts as well as identification of software constructs not well supported in the hardware. Knowledge of this sort is invaluable to a designer attempting to optimize a hardware/software design. The flow chart in figure 2 describes the functional relationship among the IDAS, the users, and the program process.

The IDAS contains extensive instrumentation to collect relevant design data, "process it down" to meaningful summaries, and present it effectively to the user. A

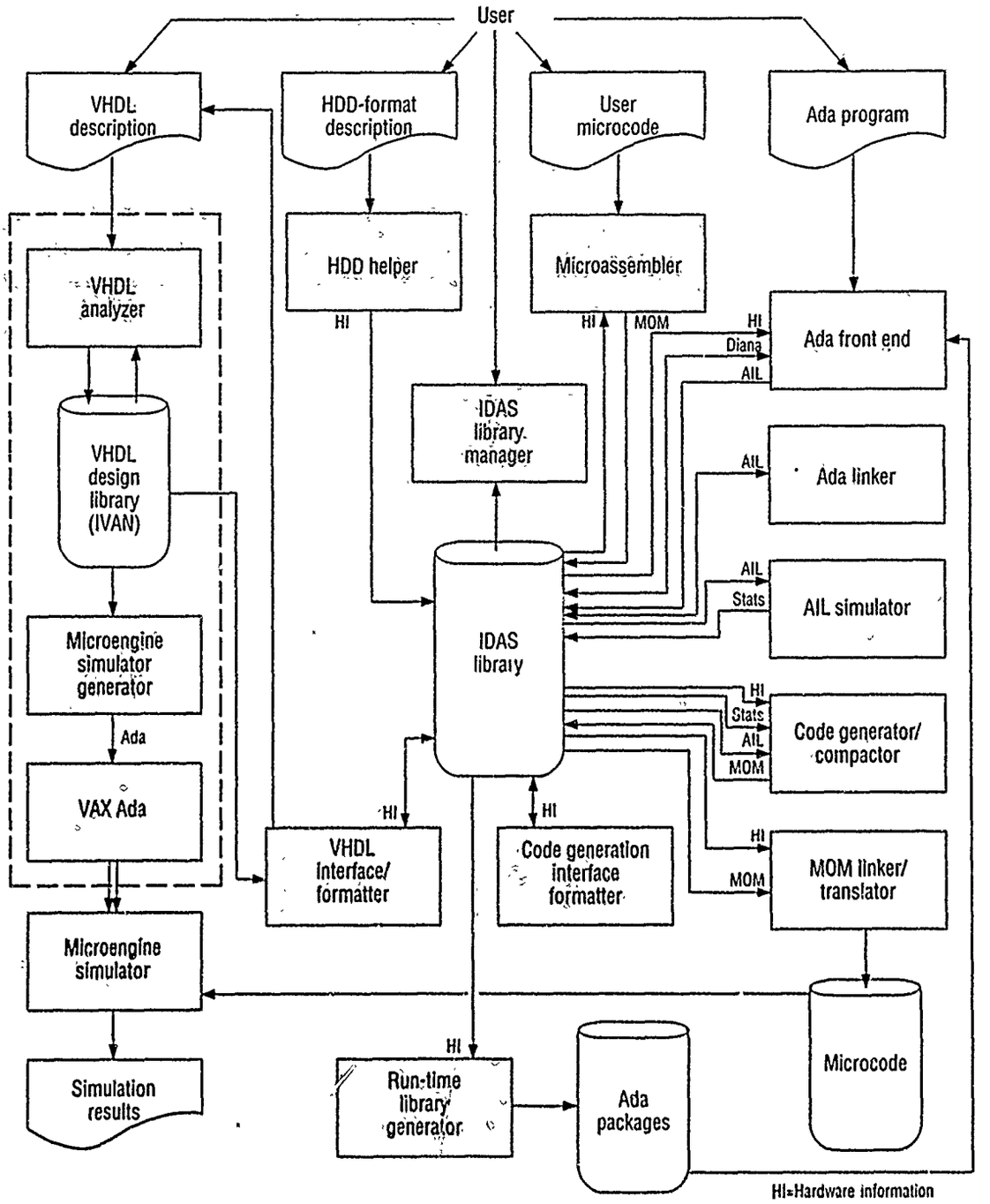


Figure 2
IDAS Functional Relationships

sophisticated object-oriented design database and multiprocessor control system allow the user to invoke automatic design analysis of one or more machines, benchmarks, or combinations thereof. Reports are given to the user with summary information which can be hierarchically accessed to give detailed information at any analysis level. Since all data can be quantitatively analyzed, design tradeoffs can be made with precision.

This work was a potential breakthrough because now architecture and algorithm optimizations can be automated. Previously, no generic quantitative approach to automating processor design tradeoffs had been available. Together, this set of tools, techniques, and concepts greatly facilitate the jobs of system designers, analysts, algorithm developers, computer designers, high level language programmers, microprogrammers, and system integrators and testers. It did so by providing the environment for a rapid prototype, evaluating hardware/software systems, and generating relevant analyses across the great span of requirements.

The IDAS resides on both the Digital VAX and the IBM PC computers. The VAX, which contains most of the computational and database elements of the system, has a VMS environment with the software implemented in Ada and Pascal. The PC's are used primarily as IDAS work-stations with all of the interactive synthesis processes and the system data entry processes residing there. The PC software is primarily implemented using Prolog and Smalltalk V.

This research was performed by Robert J. Sheraga of JRS Research Laboratories, Inc.; (714) 974-2201. The contract was administered by Harold W. Noffke, Wright Research Development Center at Wright-Patterson AFB; (513) 255-3655. ■

High Temperature Lubricant for Ceramic Bearings

The development of the high temperature gas turbine engine has obvious advantages: (1) fuel efficiency; and (2) reduction in size, weight, maintenance, and cost. The steel and composites used in current aircraft turbine engine components are unsuitable for the advanced gas turbine engines. The introduction of engineering ceramics into the material sciences has provided a sense of reality to advanced gas turbine engines.

The high thermal and mechanical stability of ceramics and their ability to resist oxidation made them prime candidates for use at high temperatures such as in the gas turbine engines. The ceramic components (rolling bearings) would increase the thermodynamic efficiency of the advanced hot engine by enabling them to operate at the extreme high temperatures.

One of the primary barriers to a successful engine development was the performance of available bearing-lubricant systems, especially under oxidizing conditions at high temperatures. For example, a typical operating environment for the main shaft bearings was that of the high temperature gas turbine engine. The liquid lubricant usually specified for the current engine bearings broke down at temperatures above 600°F. The solid lubricants, such as molybdenum disulfide and teflon, widely recognized for exceptional lubricating properties, could not be considered due to oxidative or thermal decomposition well below 1000°F. This research concentrated on the development of a self contained solid lubricated ceramic rolling element bearing that functioned under extreme conditions comparable to the advanced turbine engine main-shaft bearings.

The characteristic properties of the lubricant-bearing system had to satisfy the combined requirements: (1) environmental stability; (2) engine compatibility; (3) rolling bearing life; and (4) operational stress resistance. It also had to be effective over a wide temperature range and especially in high temperatures (1250°F plus). The lubricant had to provide wear protection under conditions of sliding and rolling contact for ceramic surfaces. The bearings were to maintain their mechanical properties over the same high temperature range and resist oxidation degradation. In addition, the bearing design had to accommodate the effective heat transfer and be compatible with engine structural materials (stationary and rotating).

The effective strategy for achieving performance and long life was based on self-contained lubrication. The approach was aimed at preventing high temperature engine bearing degradation and enhancing engine performance based on a thin, adherent, protective film that formed on the surface of the ceramic bearing.

This research formulated and tested a wide temperature range,

				TIME = HR:MIN					MAXIMUM TEMP (°F)		THRUST LOAD (LBS.)	
TEST NO.	TEST DATE	CAGE MATERIAL	RUN TIME	ABOVE 1000°F	ABOVE 30,000 RPM	ABOVE 33,000 RPM	ABOVE 40,000 RPM	MAXIMUM SPEED (RPM)	OUTER RING	CAGE	MAXIMUM	TYPICAL
1	10/2/87	RENE 41	1:23	—	0:11	0:06	0:01	42,000	780	—	41	39
2	10/9/87	CLEVITE 300	0:52	0.01	0:17	0.08	0.07	40,700	1001	—	100	85
3*	10/28/87	RENE 41	4:30	2:37	3:23	0:45	0.01	40,000	1034	1567	103	80
4	10/30/87	CLEVITE 300	3:25	1:28	2:36	2:13	0:29	50,000	1067	1500	230	200
5*	11/17/87	CLEVITE 300	6:05	3:00	4:01	3.32	—	36,600	1108	—	307	300
6	11/19/87	CLEVITE 300	3:16	1:28	2:45	2:37	1:52	42,000	1368	1720	505	400

*POST-TEST INSPECTION INDICATED THAT THE BEARING STILL HAD SIGNIFICANT, USEFUL FATIGUE LIFE.

Figure 1
High Temperature Bearing Test Results

solid lubricant as a key element for successful bearing performance in the range of 1250°F. The new and novel lubricant was a complex metal chalcogenide. Displaying properties of oxidation stability, thermal resistance, and low shear strength, this lubricant was responsive to ceramic surfaces.

Wear prevention and functional performance of rolling bearings in the non-fluid regime are dependent on the physico-chemical properties of the lubricant and bearing. This includes the presence of adherent boundary films controlling characteristics, especially the surface response at critical interfaces. The bearing ring land and separator are good examples. Interaction of the solid lubricant and bearing at these critical interfaces is the major factor in life extension for roller bearing applications.

Six ceramic (hot isostatic press silicon nitride) bearings—two with René 41 (nickel alloy) and four with Clevite 300 (iron based alloy containing cobalt and molybdenum) separators—were manufactured, coated with the complex metal molybdate-silicate solid lubricant, and tested in a high temperature bearing test rig. The application of the thin, adherent film to all parts of the bearings (outer and inner raceways, separator, lands and ball pockets) was essential to extend the bearing life.

The six self-contained lubricated ceramic bearings were individually tested in the high temperature bearing test rig under extreme conditions ranging from 1000°F 1500°F, 40,000-50,000 rpm, and thrust loads of 300 lbs. Table 1 illustrates the results.

The results of the lubricant bearing test program also showed that the interdependent concept and the complex metal chalcogenide lubricant was a vital approach to the self-contained lubricated ceramic rolling bearings to all high temperature machinery having the critical requirement for a long life, thermal-stable lubricant.

The self-contained lubricated ceramic bearing based on bonded solid lubricants presented possibilities for oil free high temperature engines. There was also versatility in using ceramic bearings in the application of solids. Thin films in combination with ceramic provided a number of design advantages. One was the weight lost by the elimination of the recirculating cooling systems.

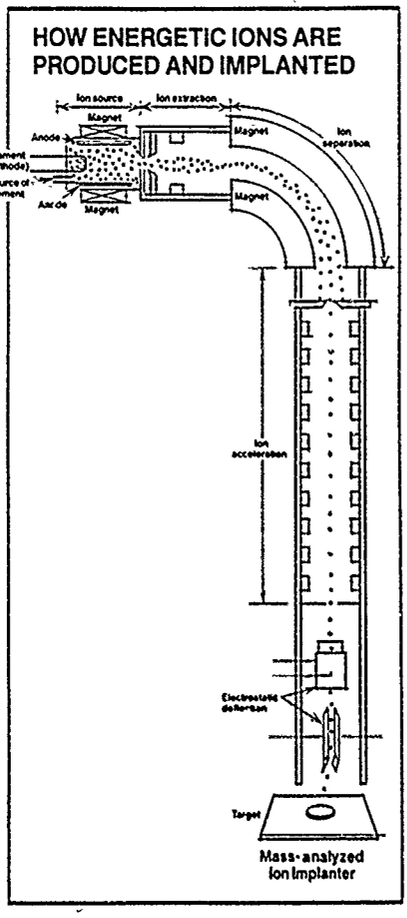
In addition to rolling element bearings, this novel lubricant could be utilized on all sliding and rolling contact surfaces, especially in machinery found in the mining, chemical processing, and electrical power industries.

This research was performed by Martin J. Devine of General Technology, (215) 446-8418. The contract was administered by Lt. Kym Malone, Wright Research Development Center, Propulsion Lab Wright Patterson AFB, (513) 255-6519. ■

Improved Properties of Transparent Plastics by Ion Beam Processes

Aircraft windows and windshields degrade, developing crazing and cracks when exposed to high-altitude environmental conditions. Conventional protective coatings on these transparent plastics tend to delaminate when subjected to thermal stress and atmospheric conditions. These problems result in a replacement or refinish of aircraft windows on a scheduled basis, thus increasing operational costs.

Ion implantation, proposed in this project, is aimed at modifying the surface properties of transparent plastics, such as polycarbonates and acrylic materials. Basically, ion implantation is a vacuum process in which an ion beam is extracted from an ion source, accelerated, and injected into the surface region of



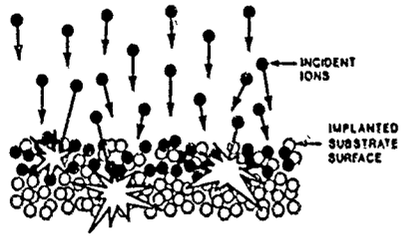


Figure 1
Ion Implantation Process

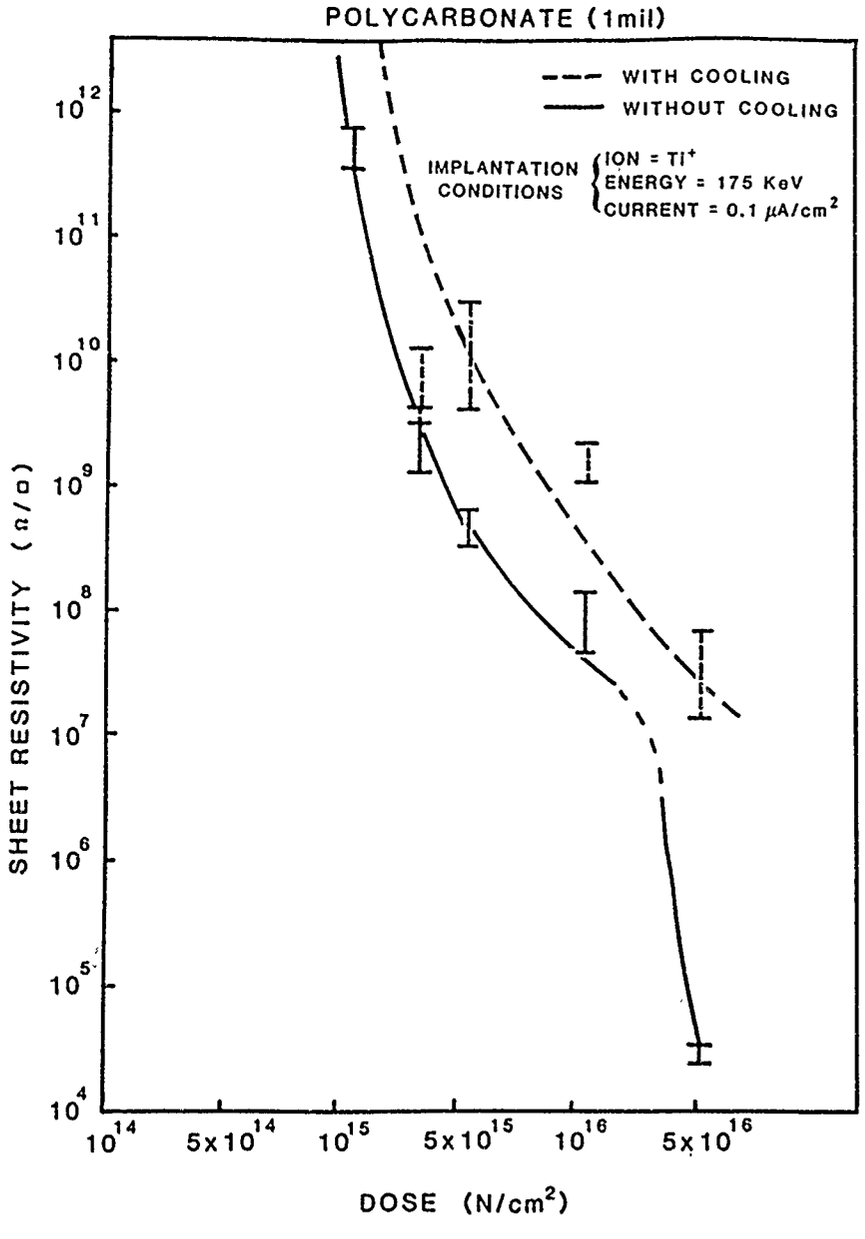


Figure 2
Sheet Restivity of Polycarbonate

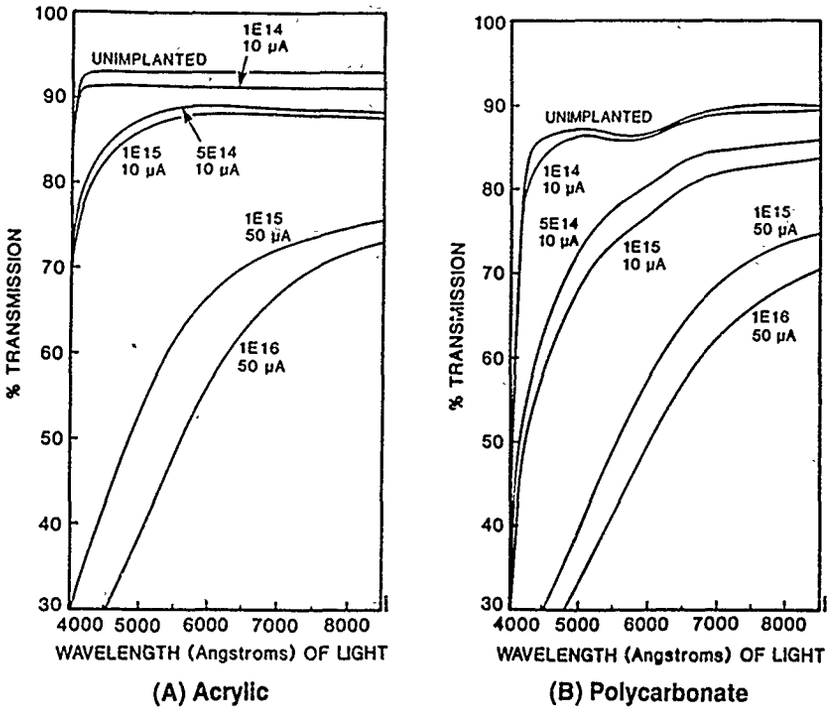


Figure 3
Transmission Curves for Aluminum Implants

a solid target as shown in figure 1. The resulting surface displays new mechanical properties and chemical resistances without changing the dimension or surface finish of the material. The process is highly controllable and reproducible. It circumvents the delamination problems associated with conventional protective coatings since there are no sharp interfaces. In addition, ion implantation is a low temperature process; therefore, it is particularly useful for surface modification of temperature sensitive materials like plastics.

Polycarbonate and acrylic materials were implanted with various ion species such as fluorine, hydrogen, helium, lithium, titanium, aluminum, and oxygen at different energies, doses, and beam current densities. The ion implantation significantly improved the surface hardness ranging from 300 to 700 percent, with other obvious differences in chemical and scratch resistance. Furthermore, the implantation process increased the sheet conductivity by a factor of a million, as figure 2 illustrates. The charts in figure 3 show how the implantation process retained the optical transmission of the transparent plastics. Figure 4 illustrates the results of an acetone solvent test on polycarbonate. The left side of the figure was implanted with titanium while the right side was unimplanted.

The improved properties of transparent plastics by ion beam treatment is expected to extend the service lifetime of aircraft windows and significantly reduce the operational cost of aircraft maintenance. The added benefits, such as scratch resistance and enhanced conductivity, offer broad potential applications in the areas of automotive sunroofs and headlight covers, electrostatic discharge plastic sheets, hard floorings for semiconductor manufacturers, face masks for the military, and a new generation of plastic bearings. The technology should be equally applicable to non-transparent plastics which offer boundless potential for protective hard coatings research, development, and commercialization.

This research was performed by Drs. Piran Sioshansi, Ping Hung Lu, and Mr. Richard Moody of Spire Corporation; (617) 275 6000. The contract was administered by Theodore J. Reinhart, Wright Research Development Center/ MLSE at Wright Patterson AFB, (513) 255-3691. ■

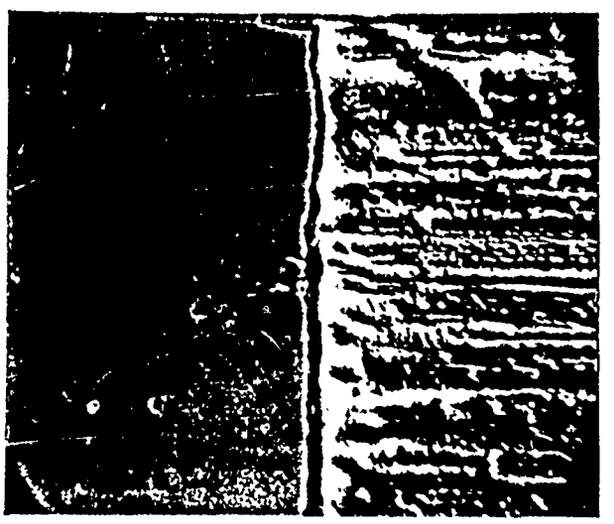


Figure 4
Solvent Test Using Acetone on Polycarbonate

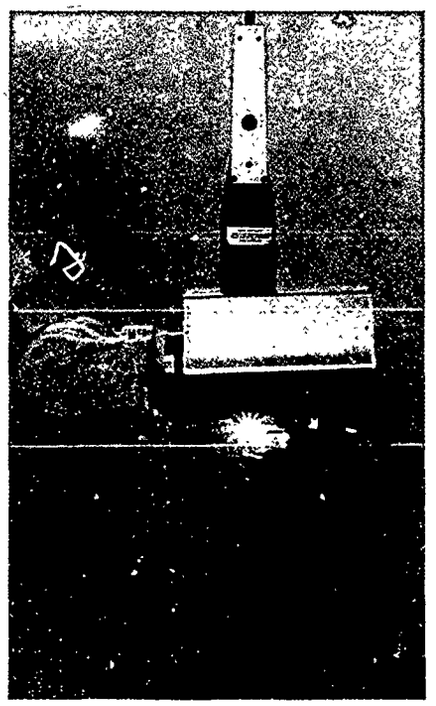
Nd:YAG Laser Robotic Workcell for Repairing Jet Engine Components

Robotic laser welding and cutting in jet engine repair is superior to manual TIG welding in that it offers improvement in speed and quality. To implement such technology within the Air Logistic Centers (ALC) environment requires that the system be very robust and user friendly. Without such features, extensive operator training or using a skilled welder would be required. This would subsequently reduce one of the advantages of switching to automation.

The goal of this project was to integrate a 400 Watt Nd:YAG laser, a Puma 760 six-axis robot, a three-dimensional machine vision system for seam tracking, an advanced real time motion controller, and an expert system material database into a laser welding and cutting workcell. Figure 1 is a schematic diagram of the workcell configuration.

The commercial laser and robot will form a test bed to demonstrate the advanced features that will allow semi-skilled operators to carry out high quality laser welding and cutting repairs on high value sheet metal jet engine components. The three-dimensional machine vision system (figures 2 and 3) demonstrated the ability to track a wide variety of joints. This included tight butt joints on metal alloys ranging from dark materials such as Hastalloy-X (a common jet engine alloy) to bright brushed aluminum.

Data showing the high quality of vision system tracking over tack welded butt joints in wire brush prepared aluminum is shown in figure 4. The tack weld is represented by the non-linear region in the center of the graph. The straight line is the path the welder took based on the processed raw data. One of the distinct advantages of the vision system is its ability to recover from failure to find the feature at any given moment. The adaptive nature of the vision software allows additional analysis of raw data in an attempt to find the feature. If this strategy fails, then the data acquisition strategy is modified to further improve the chances of properly finding and tracking the feature.



The relationship between the various vision system operating modes took place in real time with sufficient speed to keep up with the welding process. It operated at approximately ten times the speed of presently available systems, allowing many tracking failures to be discarded. Yet, it still provided a sufficient number of good tracks to follow the features. This ability is called robustness.

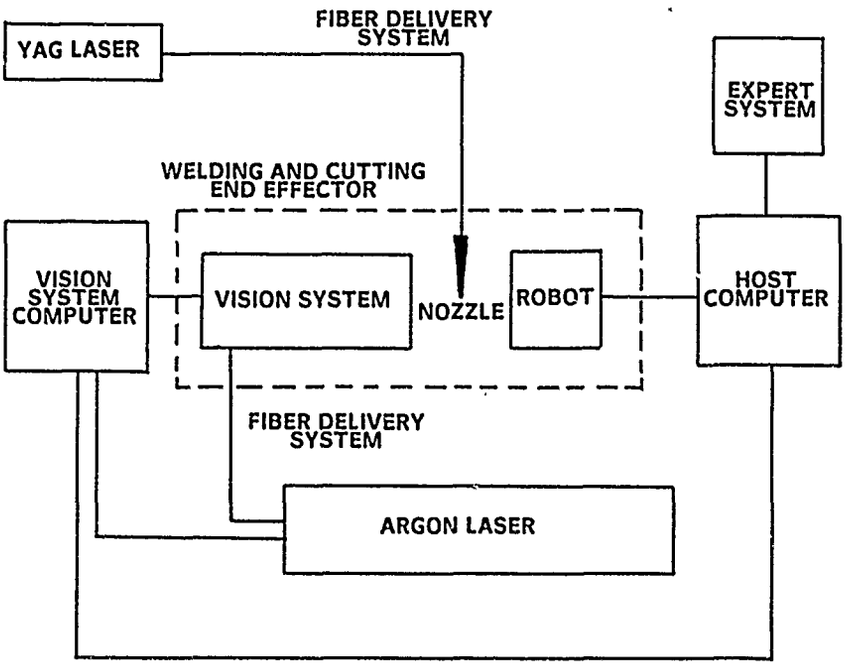


Figure 1
Schematic Diagram of Workcell Configuration

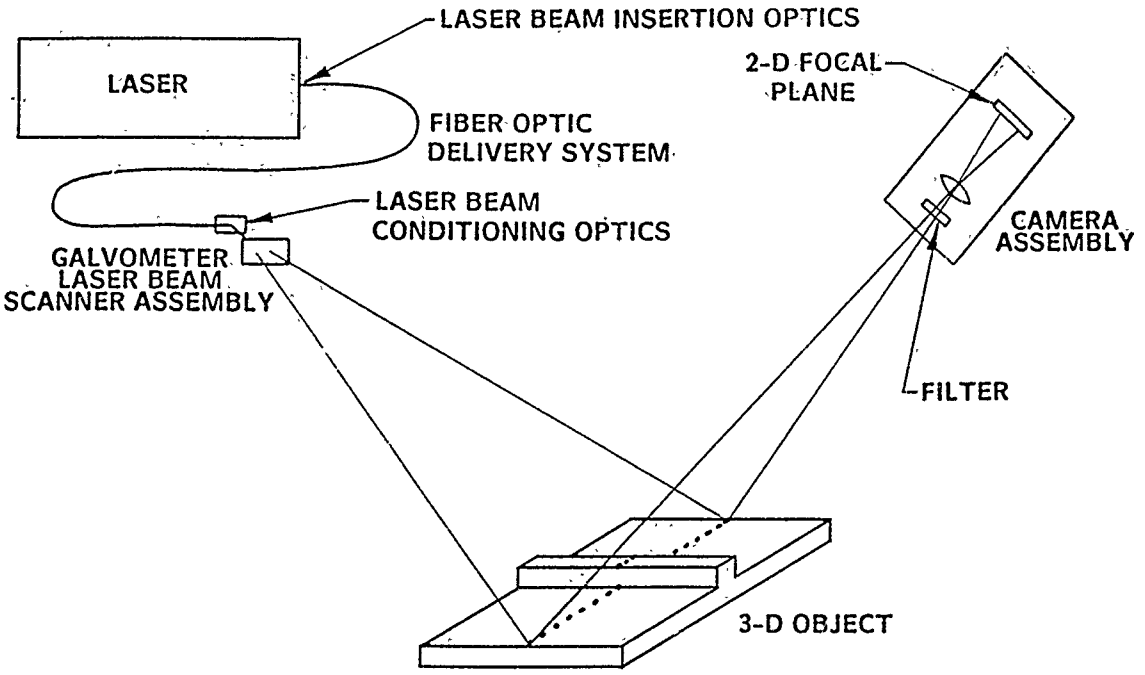


Figure 2
Search/Track Vision System

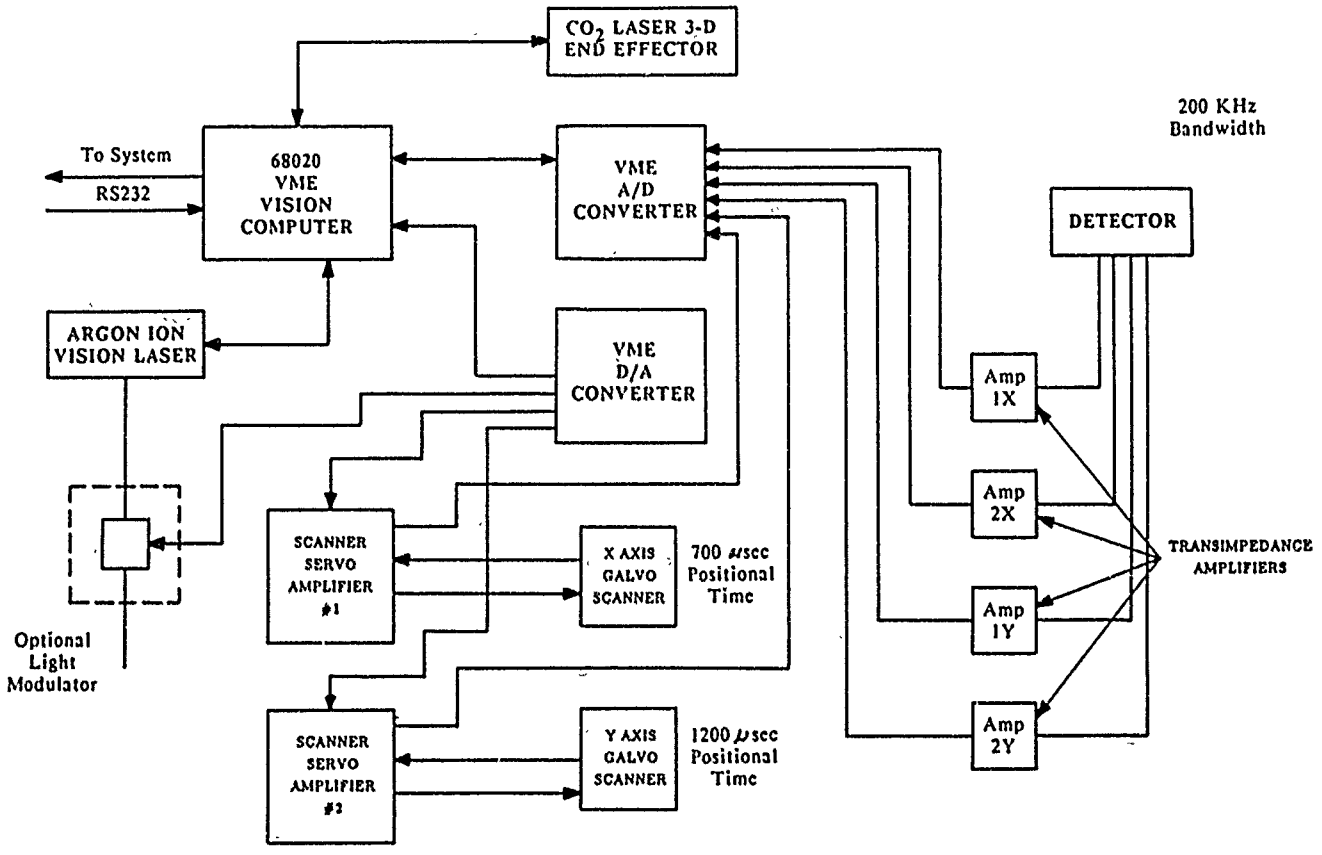


Figure 3
3-D Vision System

To utilize the information from the vision system in time to correct the robot's path, the robot controller must respond very fast. Available controllers are too slow by a factor of at least 20. The real time controller for this project updates each robot servo axis in 20 microseconds, sufficient to allow for welding speeds of up to five inches per second.

If technology were dependent on the limited number of available skilled laser welders to operate laser welding and cutting workcells, then the work would be implemented very slowly. With the use of expert systems, each system can have an "expert metallurgist and welder" built in. Thus the expert system can select the laser and robot parameters based on the material type and thickness being processed for the specific part being repaired.

Each of the advanced features described above have been demonstrated separately or integrated with other features in a limited capacity. Upon completion of Phase II, a composite integrated package will be available for commercial sale. A major manufacture of welding equipment has begun discussion with International Technical Association (InTA) for integrating the system onto their welding equipment. NASA also has a program with InTA to investigate the use of this system for welding the aluminum external tank of the Space Shuttle and the Space Shuttle main engines.

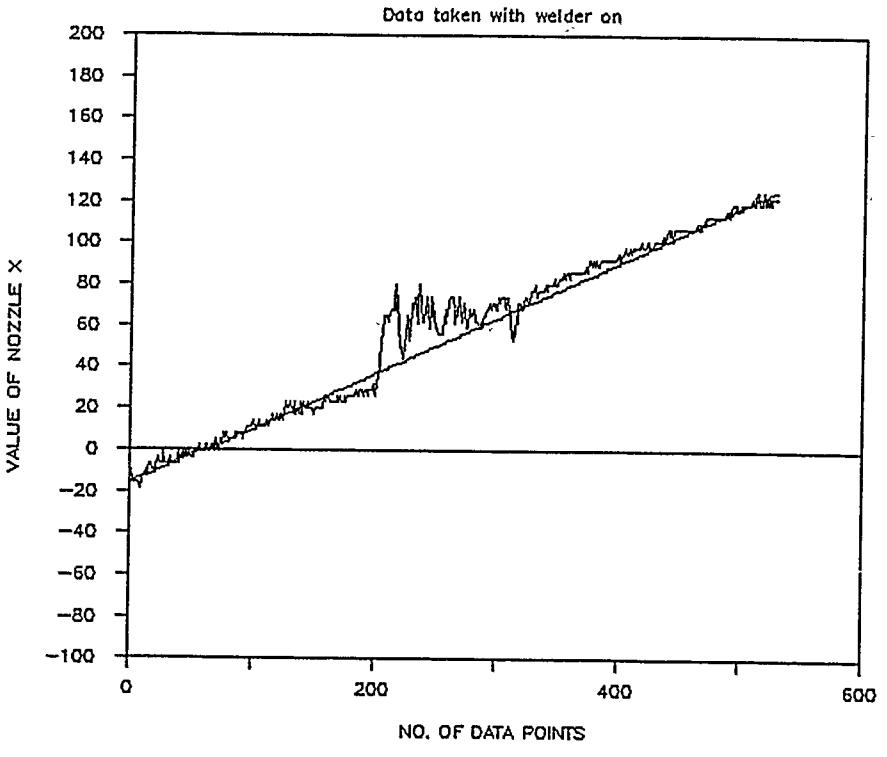


Figure 4
Raw and Filtered Data

This research was performed by Paul Lovoi of International Technical Associates; (408) 748-9955. The contract was administered by Edward Wheeler, Wright Research Development Center/MLTM at Wright-Patterson AFB; (513) 255-5037. ■

Entry Access Control Device

The Air Force Ballistic Missile Office requirement to control entry access into a restricted area demanded a rapid and accurate biometric device. This device had to possess the ability to be easily updated and to accommodate large numbers of personnel passing in and out of the area. Present systems (such as fingerprints, signature verifications, voice prints, retinal patterns, and visual checks of picture I.D. cards) were too slow and/or unreliable.

To meet this need, a Phase I feasibility contract was initiated. Later a Phase II R&D contract to construct an identity verification device was awarded based on hand geometry—using the shape and size of four fingers. An I.D. card carried the template. This template consisted of a digitally encoded electronic recording of the shape of the authorized person's fingers. In order to enter, the person inserted the card for entry access, then placed a hand on a backlighted panel as shown in figure 1. The silhouette data of the fingers were recorded by a solid-state camera and matched to the template data from the card. A perfect match received a score of 1.0. If the match score was below a pre-determined threshold, the device issued a reject decision and prevented entry access by controlling a door, turnstile, alarm or other mechanism. By the simple process of adjusting the threshold, the device could provide different levels of security as dictated by the particular entryway. The person did not need to remember a personal identification number (PIN) and no keypad was required. If the card was lost or stolen, an imposter could not use it.

The Mark III R & D model of the identity verifier consisted of a 9"x9"x9" cabinet which contained: a backlighted panel, a camera that viewed the hand silhouette, a card reader/writer, a computer board to control the camera and to compare the template data from the card with the live data from the camera, and a message panel to guide the user and to display the accept/reject decision.

The device could be used either for enrollment or entry access. The desired mode was selected on the program control. In the enrollment mode the card reader/writer became a card writer

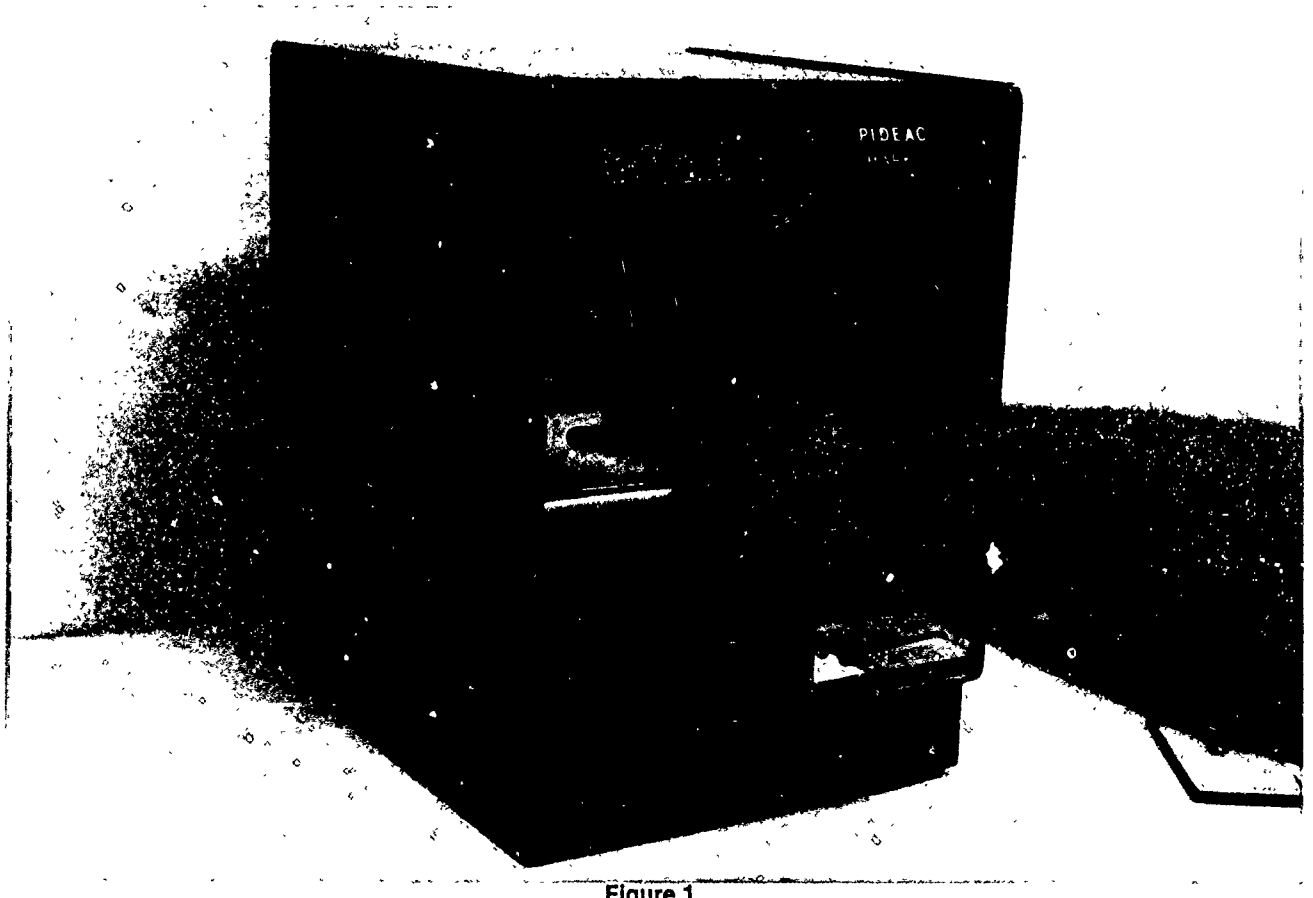


Figure 1
Mark III Identity Verifier

when it was used to record a person's finger shape data on the identification (I.D.) card. The device could be used either as a stand alone unit or retrofitted to a remote database located within the restricted area. As a remote unit, the person's I.D. card could be an ordinary badge-type magnetic swipe card containing only a PIN which served to call up the person's template from the database.

During Phase II it was established that two or more independent measures of sameness (discriminants) between two finger images increased the reliability of the accept/reject decision. The Mark III model, using one discriminant, had a Type I/Type II error rate of 1 percent. (A Type I error rejected an authorized person, a Type II error accepted an imposter.) The scan time was 7.5 seconds and decision time was 2.5 seconds for a total transaction time of 10 seconds.

The Mark IV pre-production model was based on the results from testing the Mark III. Begun under Phase II, Mark IV is being completed under Phase III with support from the State of Ohio. It uses two discriminants to make the accept or reject decision. The scan time is 1 second for a total transaction time of 3 to 5 seconds with a Type I/Type II error rate of 1 percent or better. The device will accommodate persons with fewer than four fingers on either hand and has built-in safeguards to thwart deception. For example, it can detect the presence of a paper cut out instead of a human hand.

As far as user acceptance was concerned, an important feature of the device was that no posts or other constraints on hand placement or finger spread were required. The computer circuitry automatically corrected for any modest degree of distortion. For gross positioning deviations, the message panel instructed the person to reposition the hand. Unlike some competitive devices, the Mark III and Mark IV models could accept either hand. The obvious advantage was that persons with only one hand could be accommodated. Since the I.D. card contained both right and left hand templates, the computer recognized which hand was used and could call up the appropriate template. Thus, if one hand sustained a temporary injury, the other hand would suffice without requiring the person to re-enroll.

It was of the utmost importance that the enrolled template truly represented the authorized person's fingers, otherwise, the person would be consistently rejected when attempting entry access. To avoid this circumstance, the person was repeatedly enrolled by inserting the hands at brief intervals five or more times to produce five or more templates per hand. Then the device's computer program automatically selected the best right and left templates for storage on the I.D. card, and discarded the rest.

The culmination of this effort will be a production device capable of operating in adverse climates and providing security to the Air Force and other military bases, airports, tarmacs, buildings, vaults, storage areas, computer installations, government buildings, consulates, embassies, civil and industrial facilities, and automatic teller machines. Air Force officials at a large airbase report that to provide 24-hour security guards for a single building costs $150,000 per year. Anticipated savings by converting to unmanned stations run into the millions of dollars. This does not include the savings that might result from the prevention of sabotage, terrorist attacks, and vandalism.

This research was performed by Dr. Charles Colbert, of PIDEAC, Inc.; (513)767 7425. The contract was administered by Capt. Robert E. Michael, Ballistic Systems Division at Norton Air Force Base, (714) 382-2592. ■

Development of a New Composite Material for Use in Protective Clothing

Air Force workers involved in rocket testing and missile maintenance are exposed to highly toxic nitrogen tetroxide and hydrazine propellant vapors. Protective clothing, masks, hoods, gloves, and footwear are required for these workers. Conventional protective clothing is of two types: 1) porous polymeric fabric; and 2) nonporous rubber and polymeric fabric. Clothing made from porous polymeric fabrics is unable to provide a satisfactory level of protection against vapor hazards. Clothing made from rubber or polymeric sheets can be completely impermeable to hazardous chemicals, but these materials are also impermeable to air and water, and retain body heat. When worn for extended periods, these materials are quite uncomfortable and place undue heat stress on the worker.

The goal of this project was to develop a lightweight fabric which would allow passage of water vapor and prohibit passage of hazardous vapors. The ideal material should be freely permeable to heat and vapor from the body, but completely impermeable to hazardous organic chemical aerosols, liquids and vapors. It should also be rugged enough to withstand extended use and have a smooth, non-absorbent surface to facilitate rapid cleaning and decontamination. Finally, the material should be economical to produce in large quantities and easy to fabricate into protective clothing by conventional inexpensive techniques.

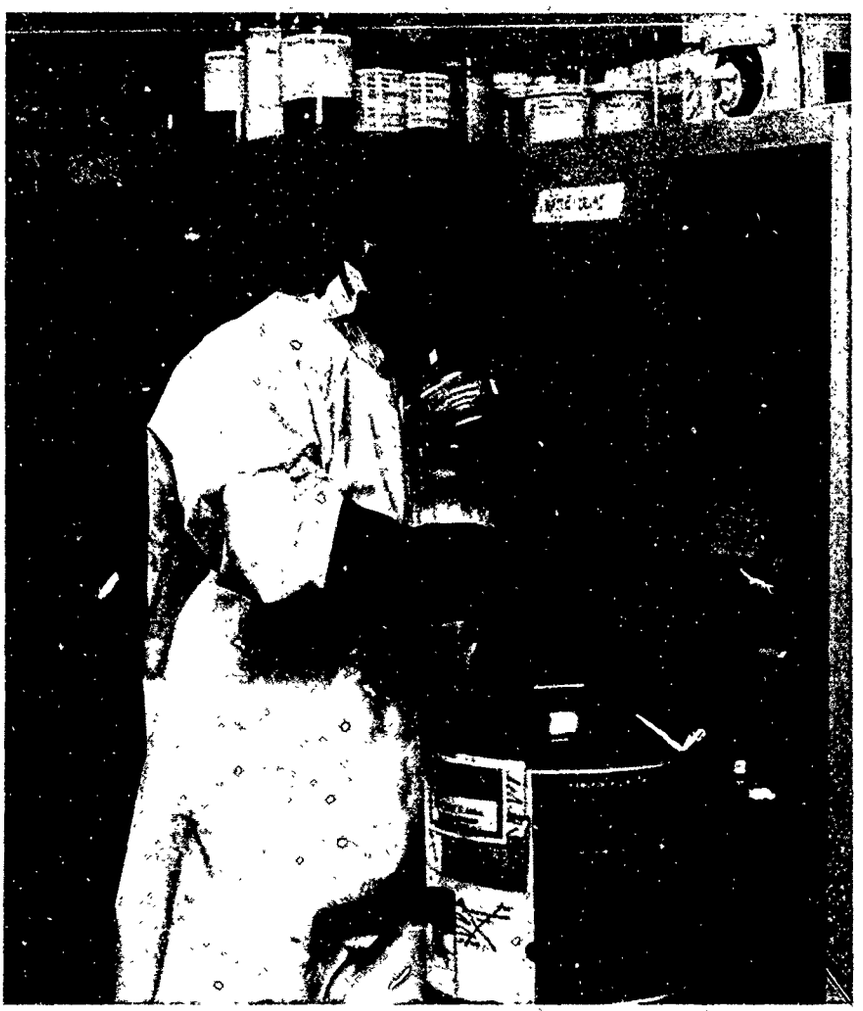


Figure 1
Prototype Protective Suit Made From MTR Composite Material

To meet the goals of this project, a synthetic multilayer composite material based on established ultrathin membrane technology was developed. The material consisted of a fabric web coated with four layers of membrane. The first layer, a microporous polymeric membrane, provided a smooth surface for the overlying ultrathin, dense polymeric layer. This layer was made from a permselective polymeric material and determined the permeation characteristics of the composite material. Because it was hydrophilic, it was permeable to water vapor but considerably less permeable to hazardous chemicals.

A sealing layer of rubbery material coated the top of the permselective layer to protect it from abrasion and seal any defects. The fourth layer, found on the underside of the fabric, was a carbon loaded material that acted as a scavenger for any hazardous vapors and was permeable to permselective layer. This composite fabric provided protection against toxic chemical vapors and was permeable to water vapor. In addition, it proved comfortable to wear.

The development of this

protective material was carried out in a two-phase project. In the first phase, candidate materials were tested against compounds chemically similar to hydrazine and nitrogen tetroxide. In the second phase of the program, the materials identified in the previous study were optimized and tested to select the components of the final material. The properties of the final material are listed in table 1.

The manufacturing process and machinery for producing the composite were scaled up during the second phase of the project. This fabric was manufactured in 40-inch widths and 150-yard lengths, and then sewn into prototype test suits, as shown in figure 1. Test suits fabricated from this material proved comfortable, even when the wearer was relatively active.

Preliminary calculations indicated that this fabric can be produced economically enough to make commercialization feasible.

The composite fabric was designed for use as protective clothing against rocket propellant vapors. However, since the permselective material is hydrophilic, it provides comparable protection against most organic vapors. Therefore, this fabric can be used as protection against solvent vapors, pesticide aerosols, and particulates, such as asbestos. Furthermore, the composite material is extremely versatile and can be adapted to different hazards by use of an appropriate permselective layer. Due to its breathability and comfort, this fabric is suitable for extended wear. Presently, a partner is being sought to collaborate in a commercial venture.

Water vapor flux (25°C)	60,000 mg/m^{2}hr (100% RH)
Nitrogen tetroxide flux (for a 500-ppm challenge for one hour)	<1 mg/m^{2}hr
Hydrazine flux (for a 500-ppm challenge for one hour)	<0.7 mg/m^{2}hr
NFPA flammability rating	Class 2 (moderately flammable)
Fabric thickness	500 m
Fabric weight	250 g/m^2

Table 1
Properties of MTR Carbon-Loaded Composite Fabric

This research was performed by Dr. Richard W. Baker of Membrane Technology & Research, Inc., (415) 328-2228. The contract was administered by Capt. James T. Betschart, Air Force Space Technology Center at Los Angeles AFB; (213) 643-0650. ■

Power Modules for Active Aperture Applications

Active Aperture Array Antennas will certainly become one of the most important techniques in achieving very high effective (isotropic) radiated power (EIRP) performance. In addition, it will govern the rapid beam steering capability in future aircraft and satellite communication links. This is particularly true for military systems. Due to the Air Force mobile platform requirements, they often use receiver terminals which are limited to very small antennas with low receive figure-of-merit (B/T).

An important ingredient limiting the full scale development of Active Aperture Array Antenna systems is the lack of a reliable power transmitter at the extra high frequencies (EHF) used in these satellite communication links. Traveling Wave Tube Amplifiers (TWTAs) offer the highest power and efficiency, but this advantage is outweighed by their limited operating life, low reliability, tendency toward catastrophic failure, high operating voltage requirement, large size, and high cost. It is clear that solid state power amplifiers will displace TWTA technology in the future. However, the solid-state Field Effect Transistors (FET) and High Electron Mobility Transistors (HEMT), devices useful at lower microwave frequencies, lack sufficient radio frequency (RF) power capability at EHF.

Therefore, the purpose of this Phase II project was to demonstrate the ability of the Impact Avalanche Transit Time (IMPATT) diode, (demonstrably the highest power EHF solid state device) to meet this requirement for reliable solid-state power amplifiers at EHF. For this project, 44 gigahertz (GHz) was chosen as the frequency of interest, since a real and current need exists at that frequency for military communication terminal uplink transmitters. The results of a design study, based upon previous work in Phase I at 20 GHz, demonstrated the feasibility of an IMPATT power module with a single stage circulator coupled with reflection topology as shown in figure 1.

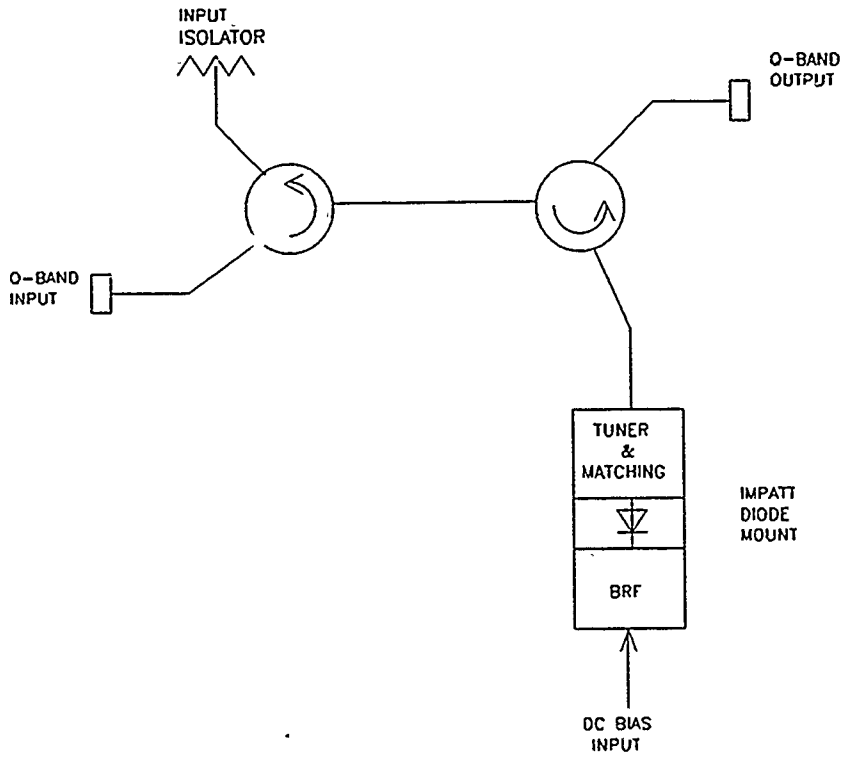


Figure 1
Single-Stage IMPATT Power Module Diagram

The key operating parameters achieved by such a design were as follows:

Center Frequency:
44 GHz
Operating Bandwidth:
2 GHz minimum
RF Power Output.
1.8 @ 0.8W drive level
Nominal Gain:
3.5 dB
DC/RF Power Added Efficiency:
10% (typical)

From the detailed design of the IMPATT power module in Phase II a quantity of 10 modules were fabricated and an extensive test/evaluation program con ducted. The test results confirmed that all the original design goals for the 44 GHz IMPATT Power Module had been achieved. The power output versus frequency response of a typical power module is shown in figure 2.

In addition to the key operating parameters, the extensive measurements conducted on the IMPATT power modules demonstrated other desirable properties for use as power output stages in a steerable multi-aperture antenna. Some of these were:

- DC bias voltage-controlled rollback of an RF output power and gain from 0-3 dB provided substantial reduction in DC power consumption while simultaneously preserving flat passband response and reducing nominal IMPATT diode junction temperature by up to one-third, resulting in lifetime enhancements of over 100:1
- wideband (~2 to 3 GHz) monotonic, well behaved albeit relatively saturated RF output power-frequency response versus input drive level, from small signal limit to full drive and wide range of terminating impedance, without spurious oscillations or distortion of power-frequency response, made possible by virtue of voltage-controlled, stable amplifier design
- negligible "load pull" effects of mismatched load on module gain and phase (with load VSWR as high as 6:1)
- transparency upon device failure, thus providing very graceful "fail-soft" capability without an excessive number of elements and permitting satisfaction of minimum EIRP requirement with as many as 40 percent power module failures
- extremely low delay distortion over full bandwidth, relating directly to correspondingly low phase distortion
- large quantity reproducibility with close unit to unit amplitude and phase tracking
- small size, light weight construction

In general, EHF active aperture phased array transmit antenna systems, utilizing IMPATT diode power amplifier modules to drive the individual array elements, provided the advantages of rapid beam scanning or hopping capability and graceful degradation rather than catastrophic failure modes. By using IMPATT diode power amplifier modules with 1.5 watt (minimum) power output capability at 44 GHz to drive each of the individual radiating elements, it provided maximum EIRP per element. Also, it should be noted that it required fewer elements to achieve a given total EIRP, while simultaneously providing built-in amplitude weighting and EIRP backoff capability per module. This program demonstrated via implementation and extensive measurements that 44 GHz IMPATT amplifier stages, operating over bandwidths exceeding 2 GHZ, are feasible for active aperture antenna applications.

In addition to the realization of the program goals for active aperture antenna applications, the development of a 44 GHz solid-state IMPATT Power Module was important for other potential uses. Using frequency scaling methods, the same technology developed for 44 GHz could be extended to other frequencies in the EHF band, e.g., 30, 60, and 95 GHz. Moreover, by various methods of power combining the individual IMPATT modules could be used as building blocks and configured to form a "single thread" power amplifier. This would provide higher output power ranging from 5 to over 20 watts. Such solid-state high power IMPATT transmitters have broad application in both spaceborne and ground-based portions of military and commercial satellite communi cation systems.

This research was performed by Johannes deGruyl and Dr. H. C. Okean of LNR Communications, Inc; (516) 273-7111. The contract was administered by Robert Blumgold. Aeronautical Systems Division at Wright-Patterson AFB; (513) 255-7690. ■

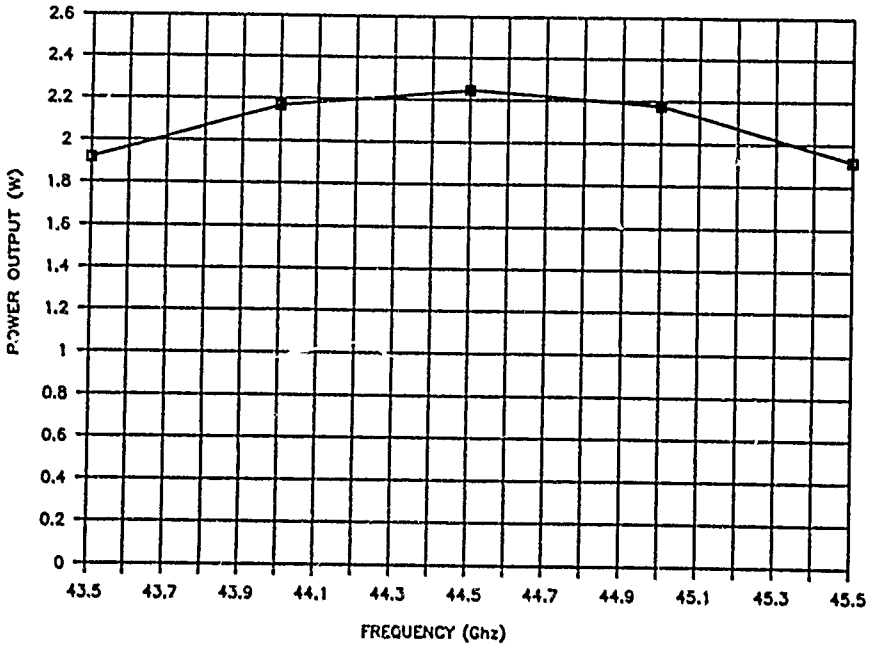


Figure 2
Power Output vs. Frequency Response

Evaluation of the Permeable Base Transistor for EHF Performance

The Air Force need for devices capable of operating in excess of 94 gigahertz (GHz) made the Permeable Base Transistor (PBT) a possible candidate for extra high frequency (EHF) operations. Gallium arsenide PBTs are currently being fabricated in the U.S. The objective of this project was to conduct a design-oriented numerical simulation study in order to evaluate the suitability of the PBT for EHF applications and to suggest design modifications to accomplish high frequencies.

A unit cell of the PBT is shown in figure 1. The PBT consists of an array of many such cells. Seven design variables related to the structure are illustrated in figure 1. They are: the depth of the cell (D); height of the base (d); height of the channel (h), thickness of the base (L_B); length of the device upstream of the base (L_{BE}); length of the device downstream of the base (L_{BC}); and the total length of the device. The design variables related to the process are choice of material (which is gallium arsenide) and the doping. Variables related to the operation of the device are applied voltages on the emitter, base and collector contacts, power to the circuit, etc.

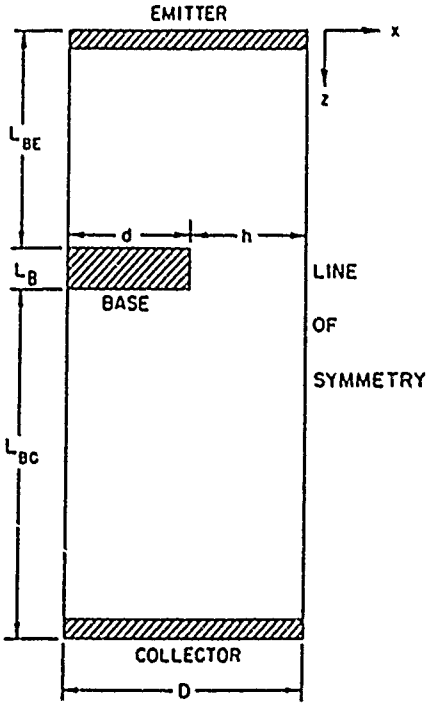


Figure 1
Unit Cell of the PBT

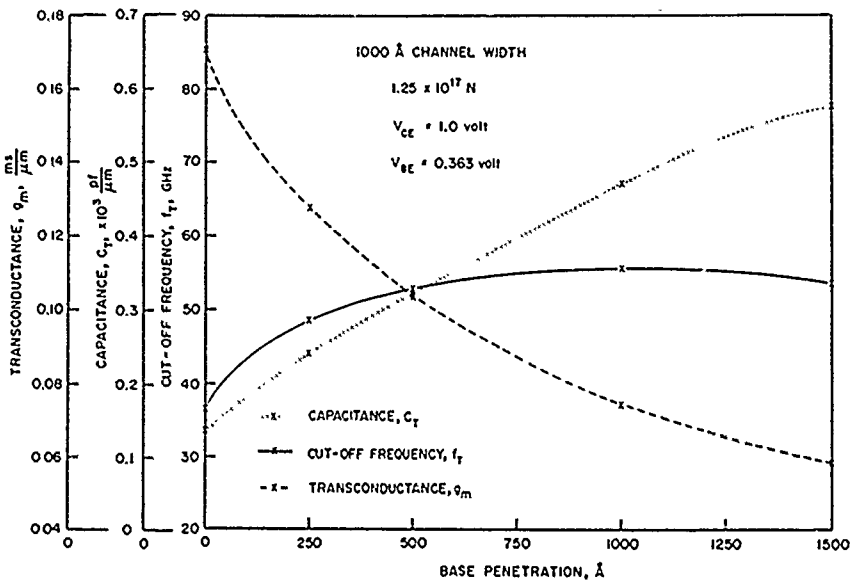


Figure 2
Device Performance Dependance on Base Height

It is clear that the number of variables is large, resulting in an expensive trial and error procedure to develop structures capable of EHF operation. Hence, computer simulations based on sound fundamental concepts can be a cost-effective adjunct to the fabrication of new devices. For the effort to be useful and realistic, it must be closely coupled to device fabrication programs.

A large number of simulations were performed using a semiconductor drift and diffusion computer code. This code was capable of solving, in multi dimensions, the drift and diffusion (DDE) and Poisson's equations. These equations described the physics of semiconductor devices, subject to certain approximations. The parametric study conducted involved a systematic variation of the value of a specific design variable while keeping all other parameters constant. Such sensitivity studies enhanced the understanding of the effect of that variable on device performance. For example, when the base height (h) was varied from 0 to 1500 Angstroms, the device figure-of-merits varied widely. This is illustrated in figure 2, where frequency of operation, transconductance, and capacitance are plotted as a function of various base heights. Results from several individual studies were finally used to identify a range of variables capable of meeting requirements, such as achieving 94 GHz or above.

Since the drift and diffusion equations (DDE) contain certain approximations which restrict their use for submicron devices, additional computations were performed for the PBT using moments of the Boltzmann transport equations (MBTE). The MBTE did not have the restrictions of the DDE and applied to submicron devices. The MBTE solutions provided additional insight into the operation of the PBT.

The results of the simulations using DDE and MBTE were used in the effort to fabricate the PBT. One of the major accomplishments of this study was a modification of the PBT structure as shown in the elliptical region in figure 3. The innovation was the use of semi-insulating material in a region surrounding the base contact instead of the conventional semi-conducting gallium arsenide. Our simulations showed that the current typically flows around the base contact as illustrated in figure 4. This is very similar to the flow of water in a pipe containing an obtrusion. The electrons immediately upstream and downstream of the base were not participative in conducting current. Hence, they were parasitic to device operation and degraded the performance. Replacing the semiconducting material surrounding the base with semi-insulating material improved device operating frequency. The modification design (figure 3) yielded a cut-off frequency of 81 GHz, while operating the corresponding conventional structure showed a frequency of 61 GHz.

In summary, a design-oriented computer simulation of the permeable base transistor was conducted to study the identified parameters capable of yielding high frequencies for EHF applications. PBT also proved to be a cost-effective design aid and adjunct to the fabrication efforts of other Air Force contractors.

This research was performed by Dr. Meyya Meyyappan, John P. Kreskovsky and Harold L. Grubin of Scientific Research Associates, Inc.; (203) 659-0333. The contract was administered by Dr. Gerald Witt, at the Air Force Office of Scientific Research at Bolling AFB, (202) 767-4931. ■

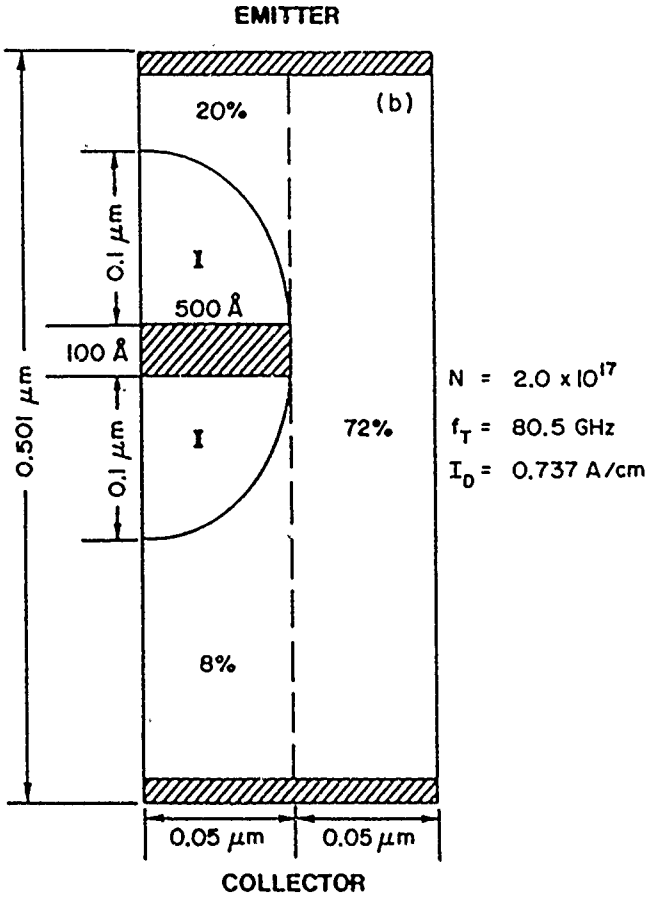


Figure 3
Proposed Innovation

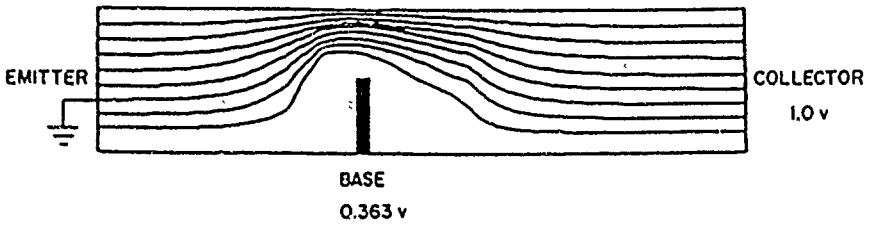


Figure 4
Current Flow Inside the Device

Eliciting and Structuring Expert Judgment in S/V Analysis

It is essential that the Air Force be able to predict the Survivability and Vulnerability (S/V) of structures and their contents. Direct testing of the S/V of buried concrete structures exposed to blast and shock waves is time consuming, expensive, and often not feasible. The major focus of this research was to develop formal methods for using existing data to accurately predict S/V. The data, by helping engineers make predictions and analyses, would in turn aid in design improvements for structural performance.

Figure 1 shows a concrete structure that was buried, tested, and then measured for damage. It is interesting to note the strain gauge and the cracks in the structure wall and floors. Formal simulation models of the buried apparatus are difficult to run. In addition, training structural engineers to perform and interpret a model is difficult. There is a great advantage in using data from prior tests. These tests, unfortunately, were performed to answer specific questions and do not serve as a jumping-off point for future estimations. In light of all the resources committed to previous testing programs, development of a procedure that takes advantage of earlier work would be valuable. It could also point the way to reporting future research so that findings can be more readily utilized.

Phase I examined the feasibility of using a Comparison Based Prediction (CBP) method for drawing on earlier research to

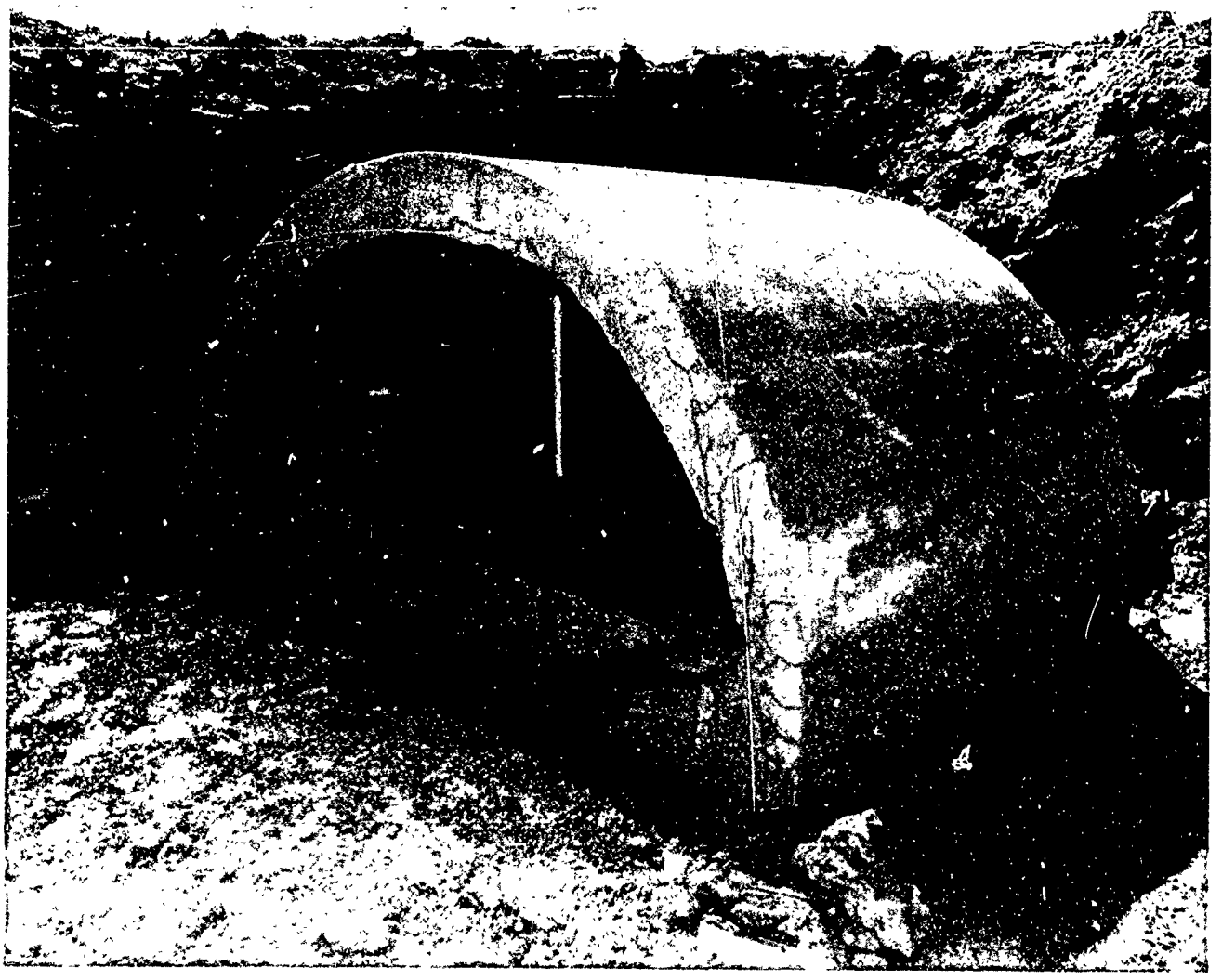


Figure 1
Concrete Tested Structure

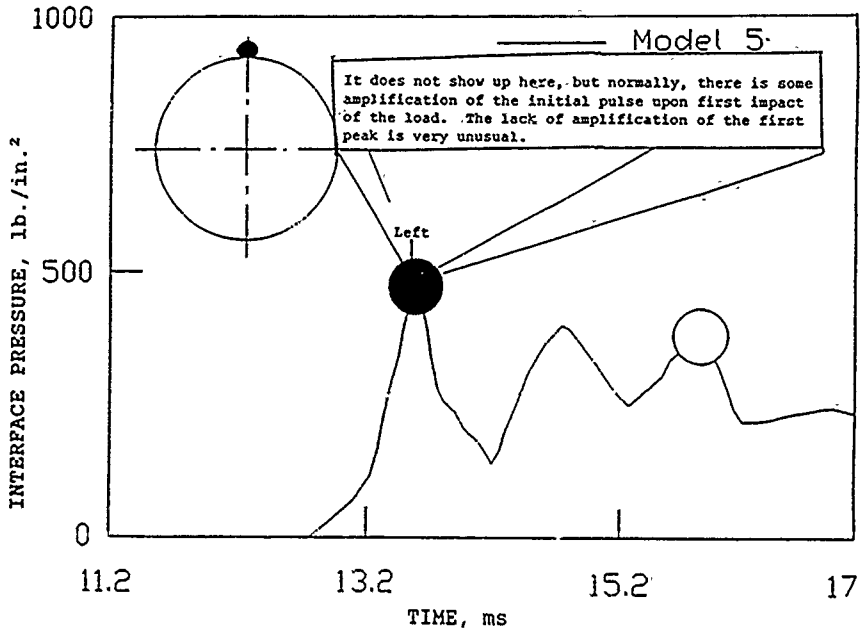


Figure 2
Surver II: Graphical Data for Structural Engineers

generate predictions about S/V. The results showed clearly that prior test data was usable for making predictions. The estimates generated by domain experts using previous cases showed a large reduction in variability.

The primary objective of Phase II was the development of strategies for training new structural engineers by extending the Phase I Comparison Based Prediction application in three areas: 1) development of an expert system for retrieving prior cases that match new configurations and for guiding the analyses; 2) refinement of the CBP method for eliciting information from domain experts; and 3) development of a case-based training program for structural engineers. All three objectives were accomplished successfully, resulting in the Air Force Weapons Laboratory having a new training system.

The first objective was to develop a prototype of an expert system for retrieving and interpreting prior cases. It features an innovative retrieval algorithm. (Retrieval is often the most difficult aspect of using prior cases.) The prototype system runs on the Zenith 286 computer and combines frame-based and rule-based components to select cases. It also recommends ways of modifying the cases to meet the parameters of a new situation. This work represented what may be the first application of case-based reasoning principles in a military domain.

The second objective was to refine the CBP method so that it was a more effective knowledge engineering tool for deriving information from domain experts. By focusing on the way experts identified relevant prior cases and the strategies they used to adjust these cases, improvement to the CBP method as a means of developing a knowledge-based system was made. Complex graphical data is shown in figure 2. Structural engineers use this data to predict the outcome of nuclear blast damage to buried concrete structures.

The third objective was to develop a case-based training program for structural engineers at Kirtland AFB. The bulk of the effort went into coding prior test data into a graphics data base so that new engineers could analyze the results of their computer simulations by looking at the pattern of prior tests. The training system enabled the engineers to click on key features of the curves; thereby obtaining an explanation of the dynamics of the previous cases. The result was a training program that builds on previous findings to guide engineers through the interpretation and analysis of data. The interface uses dBase III and a Microsoft Windows environment to facilitate inspection and comparison.

The key product developed under this project was a case based training system that runs on a Zenith 286 Computer and takes advantage of existing data bases. This system also serves as a model in other domains. A second product is the prototype case based reasoning system which includes the new retrieval algorithm. Lastly, the most important product of case-based reasoning is the possibility of it being a significant technique for developing knowledge based systems in a variety of military application areas.

This research was performed by Dr. Gary A. Klein of Klein Associates, Inc., (513) 767 2691. The contract was administered by Tim Ross and Aaron Perea, Weapons Laboratory at Kirtland AFB; (505) 846-6467. ■

Pilot Loss of Consciousness Monitor

A two-phase effort to develop a sensor which could reliably detect the eyeblink of pilots in high performance aircraft was undertaken. The sensor (named PLOC for Pilot Loss of Consciousness) was designed to trigger an alarm signal upon the cessation of the pilot's involuntary blink response as it would occur during a period of unconsciousness. Requirements for the device were that it be small, low powered, lightweight, and as unobtrusive as possible to the wearer.

The major objectives of this Phase II research and development effort were to overcome mechanical and electronic deficiencies, which remained following the Phase I feasibility study, and to miniaturize the PLOC device for helmet mounting. Major conceptual changes were implemented in the PLOC design during the Phase II effort to improve the accuracy of blink detection. Significant hardware changes allowed the system to eliminate unwanted electrical and optical noise while simultaneously providing for increased sensitivity and dynamic range.

A third optical channel was added to the device providing a visible indicator to the pilot or equipment technician to assist in the mechanical aiming of the optics. This channel is active for only a few seconds after donning the helmet and mask. The PLOC device was relocated to the oxygen mask instead of the helmet as suggested in Phase I. The

Figure 1
Eye Sensor Device for Pilots in High Performance Aircraft

change made the concept feasible by providing a method of mechanical mounting and eliminating field of view restrictions. A custom fiber optic cable assembly was designed and constructed to provide the interface between the eye being monitored and the transducer electronics. Suggestions from the end user were incorporated into the design to make the device simpler to align and operate.

The location of the PLOC device needed some consideration. Due to the fact that the size required for the fiber optic cables were both heavy and inflexible, the cable was kept as short as possible. This meant mounting the emitter, driver, detector/receiver, and amplifying circuits in a small area beneath the pilot's chin. In order to minimize the weight, the electronics assembly was cast in a protective housing using a mixture of polyester resin and a high percentage of hollow glass spheres. A cable passed the various data and control signals to the transducer as shown in figure 1 A small aluminum box houses the remaining electronics and provides a mounting point for the plug connection to the aircraft power and avionics systems.

The PLOC concept, a microprocessor device that can reliably detect the presence or absence of the eyeblink response under a wide range of environmental conditions and on a wide range of subjects, was finally realized. Many additional improvements can be made to PLOC which would require only a minimal additional design effort. In its final form, the PLOC should be capable of detecting 99.9 percent of all eyeblinks while at the same time rejecting 99.9 percent of all false alarms due to cockpit ambient lighting conditions or motions of the pilot. Suggested improvements for production models of the device include: 1) eye blink characterization; 2) improvement in signal-to-noise ratio; 3) miniaturization; and 4) fixed or variable timing specifications.

Modifications in the microprocessor firmware can significantly improve the characterization of the individual eyeblink. In this fashion, the blink "template" (empirically determined) can be substantially improved (in real time) and the device can be made to adapt to minute differences in the pilot's habits.

Further improvements in the signal-to-noise ratio can be achieved, if the pilot wears either a reflective or non-reflective coating on the eyelid. The difference in reflectivity between the eyelid and the actual surface of the sclera, while detectable, is quite small and could prove difficult to detect on certain individuals. Eventually, full scale testing should take place using subjects with every possible combination of skin and eye coloration. Limited laboratory testing using a reflective coloring on the eyelid yielded a dramatic improvement in signal-to-noise and contrast ratios. Although this concept was not originally proposed, it is felt that this simple addition could have a positive effect on the overall reliability of the system. The PLOC electronics and software could be made to accept either reflective (light/metallic) or non-reflective (dark/black) coatings.

With the availability of new technologies and components, additional miniaturization is possible. In volume production, the small aluminum housing for the power supplies and microprocessor could be eliminated entirely, with those components becoming an integral part of the transducer electronics assembly.

Centrifuge testing should be performed to determine the length of time that should elapse before the system produces the loss of consciousness alarm. An important consideration is whether this function should be set into hardware (fixed) or if it must remain variable. The same is true of the visible LED signal used for aiming the device. Production models could be fitted with small switches if necessary, although mechanical switches would lessen the overall system reliability. The current prototype hardware provides a means to change these timing functions; however, the microprocessor must be removed from its housing.

This research was performed by John A. Stokes of Energy Optics, Inc.; (505) 523-4561. The contract was administered by Dr. Van Patten, Armstrong Aerospace Medical Research Laboratory/ Human Systems Division at Wright-Patterson AFB; (513) 255-3742. ■

Simulated Ground Response Using Non-Linear Elastic Moduli

When soils are subject to strong shaking, such as from a nearby earthquake, they experience a loss in shear strength and an increase in energy absorption. In order to design structures in soil which will survive strong shaking events, soils engineers require knowledge of the change in soil properties with strain level. The general trend of the strain-dependent properties for different soil types is known from laboratory measurements, but each site has unique characteristics which must be evaluated on a case-by-case basis. Traditionally, this has been accomplished by performing laboratory tests on borehole samples from different depths in the soil column.

While laboratory measurements allow a wide range of parameters to be varied under controlled conditions, they suffer from the major disadvantage that, during collection, the soil sample is invariably disturbed to some degree. As a result, low strain laboratory values of shear modules often disagree with field measurements. Because, however, in situ soil properties at high strains are difficult to measure, soils engineers have traditionally used the laboratory results to define the shape of the modulus reduction curve, adjusting the curve up or down to match the low strain field values.

This problem was overcome by the development of a fast, efficient, field technique. The technique measures shear modulus and damping values in soils in situ over strain levels comparable to those used in laboratory testing (10^{-4} percent to 10^{-1} percent). It consists of analyzing seismic surface waves generated by a falling weight and recorded on the surface using closely spaced velocity-sensitive geophones. Large shear strains, generated within 10 - 30 ft of the source, cause a reduction in the shear velocity of the near-surface material which, in turn, reduces the phase velocity of Rayleigh waves. The velocity reduction can be measured by fitting a theoretical curve to phase arrival times over a frequency band of approximately 20 to 40 cycles per second. The peak particle velocity of the surface waves can also be measured, which, together with the computed phase velocity, allows an estimate of the shear strain to be obtained.

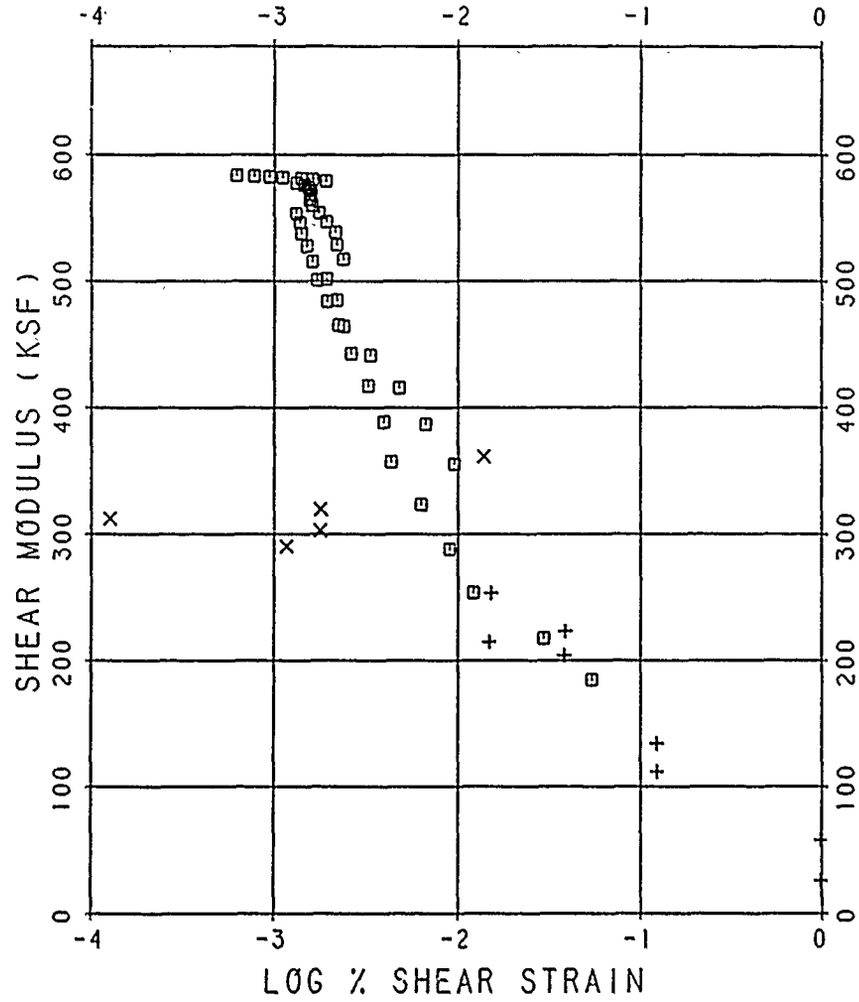


Figure 1
Shear Modulus Reduction with Increasing Strain for Clay Site

Thus, in figure 1 a curve showing reduction of shear modulus with strain can be derived. The open squares were obtained using the in situ method described. The other symbols were values from laboratory tests

on samples from 10 18 ft depth in the soil column (x = Resonant Column, + = Cyclic Triaxial). The field and laboratory values agreed well for strains above 10^{-2} percent, but the laboratory values were a factor of two smaller than the in situ values at smaller strains.

Estimates of internal damping may also be obtained at different strain levels by analyzing the decrease of trace amplitude with distance from the source. In the analysis, a correction needed to be made for geometrical spreading of the wavefront, which also caused a reduction in amplitude. It was found that the far-field geometrical spreading term for Rayleigh waves gave unreasonably large damping values at high strain levels. Near the source, other terms were required in the geometrical spreading formulation in order to keep the damping levels within reasonable bounds. An ad hoc correction method was developed, which gives acceptable results as illustrated in figure 2.

This chart reveals the damping values for the clay site. The same symbols are used as in figure 1. It reveals the empirical curves compiled by Seed and Idriss (Earthquake Engineering Research Center, University of California, Berkeley, Report EERG 70-10, 1970) and shows the range of damping values in clays measured on laboratory samples. The in situ results complement both sets of laboratory data. However, further theoretical work is needed to justify this part of the analysis.

Because only surface sources and receivers are used, the technique can be rapidly deployed and avoids the cost of drilling boreholes. Derived soil properties are generally representative of the upper 20 - 30 ft of the soil column. The near-surface region is where the largest strain levels occur and where most structures are built. Near-surface soils are also generally most difficult to sample for laboratory determination of dynamic properties. The in situ method presented here can therefore be used on a stand-alone basis or as a complement to other methods used to predict the dynamic earthquake response at a particular site.

Results indicate that the in situ method is most successful for soils with shear velocities less than about 1000 ft/sec (300 meters/sec). Above this limit, the strains required to produce a significant modulus reduction were larger than can be easily generated and measured in situ. The 1000 ft/sec limit, however, encompassed most normally consolidated soils and should therefore not be a barrier to useful implementation of the need. The development of the method, including its application to a range of soil types, and the compilation of a catalog describing dynamic soil properties which can be used by soils and earthquake design engineers, is in progress.

This research was performed by Dr. Glyn M. Jones of Weston Geophysical Corporation; (508) 366-9191. The contract was administered by James C. Battis, Geophysics Lab/LWR at Hanscom AFB; (617) 377-4870. ■

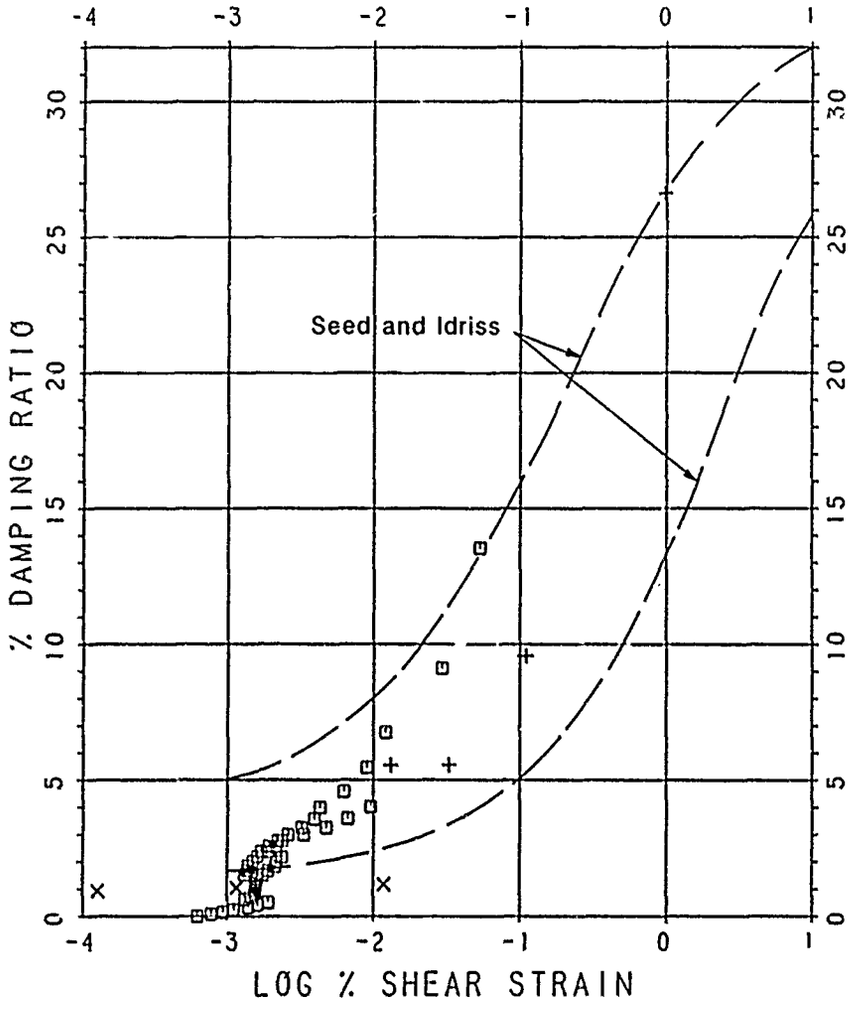


Figure 2
Damping Values for Clay Sites

All Solid-State Integrating Dosimeters

In recent years there has been a rapid increase of knowledge concerning the nature of radiation fields surrounding the earth. The composition of this radiation field includes gamma rays, protons, electrons, neutrons, alpha particles, and ionized atomic nuclei. This wide range of radiation covers a broad energy spectrum which ranges from less than 1 MeV to over 10^6 MeV. The intensity of the radiation fields vary by many orders of magnitude even during near-earth missions. They depend on factors such as the altitude and latitude of the flight path and the current level of solar activity.

The difficulty of ensuring radiation safety during space missions arises both from the nature of this environment, and the limitations on the weight and material of flight vehicles. It is simply impossible to block all radiation from reaching the flight compartment interior. In addition, the absorption of the high energy primary radiation by the vehicle shell results in the release of secondary radiation, which can also provide a major contribution to the dose experienced inside the living area. This environment, with its complexity of charged particles and numerous secondary interactions, presents a formidable dosimetry challenge.

There are three major natural sources of exposure in the near-earth environment. They are the earth's radiation belts, solar radiation, and galactic radiation. The earth's radiation belts consist mainly of protons and electrons captured by the geomagnetic field. The intensity of the flux is known to vary widely with altitude and angle of inclination of the orbit. The second major source of exposure, the high energy radiation of solar origin, is composed mainly of protons and alpha particles. Finally, the third source of radiation, which originates from galactic sources, is composed mainly of protons with some alphas and heavier nuclei.

The primary radiations produce secondary emissions in the form of neutrons and x-rays inside the vehicle. The most significant source of x-rays encountered in the space environment is Bremsstrahlung radiation. It is produced by collisions of high energy electrons (found in the earth's radiation belt) with the spacecraft walls.

Since the beginning of successful spaceflight, a wide variety of passive and active radiation detection devices and dosimeters have been flown on

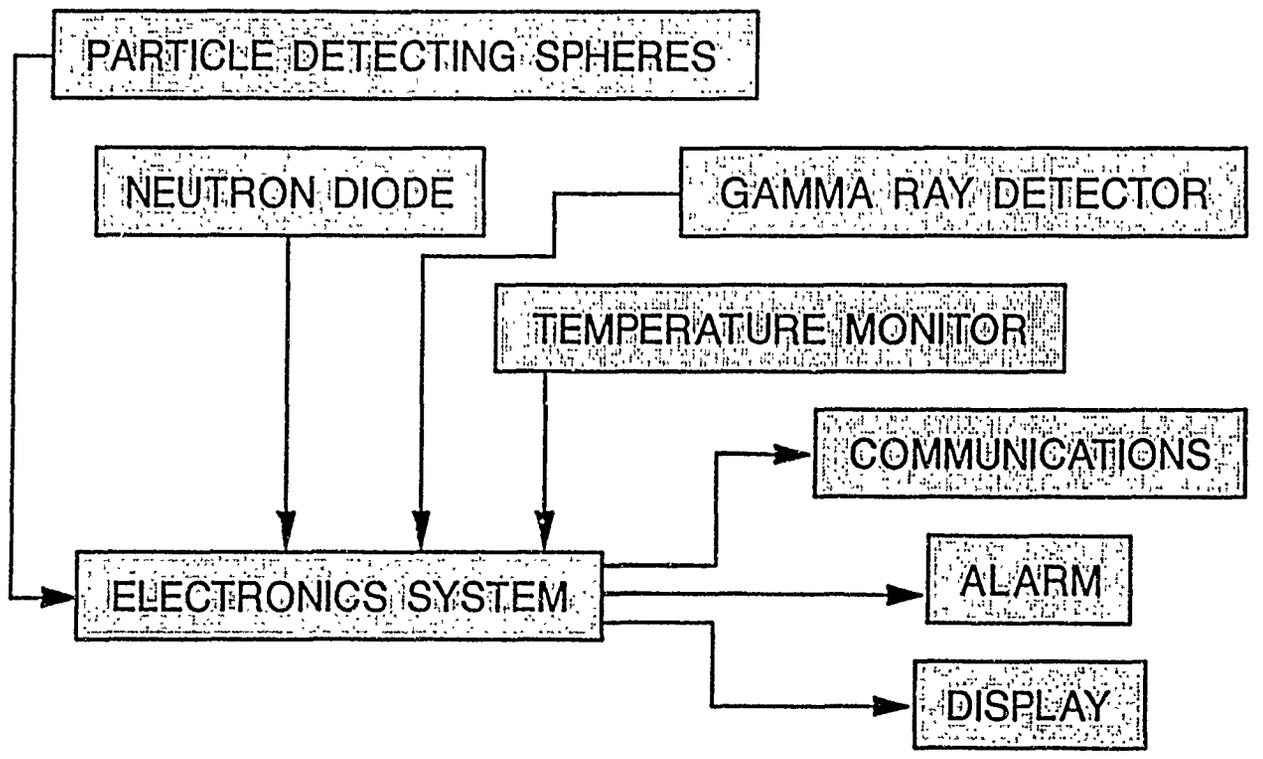


Figure 1
System Block Diagram

balloons, unmanned satellites, and manned missions. The purpose of this work was to develop a solid foundation and understanding of the nature of the radiation fields surrounding the earth.

The earliest types of detectors flown were simple passive detectors such as plastic nuclear track detectors and fission-foil detectors for neutron measurements. These devices performed well and provided the measure of total dose and count rates. However, they were not able to differentiate the dose delivered by each radiation type. In addition, it was impossible to record the time course of the dose delivered to the inside of the spacecraft during the course of the mission. Other drawbacks of these detectors were that they tended to be large, required high voltages, and drifted with time.

Other experiments used solid-state detectors to monitor the radiation dose. Radiation emission resulted from electrons, protons, and nuclear star events coupled with the differential and integral fluxes of electrons and protons. This was a significant advance, because solid-state detectors were small, lightweight, low powered, and immune to magnetic fields. Therefore, the detectors became very attractive for space instrumentation.

The recent advances in detector and electronics technology indicate that it is now possible to develop a small self-contained microprocessor-controlled instrument. This instrument would use only solid-state detectors to monitor the radiation exposure from the major radiation types inside the spacecraft living area. The microprocessor would then make it possible to calculate the dose in real time, store the time course of exposure, and display the integrated dose data with an alarm function to inform the flight crew of their exposure level.

Current research focused on the development of an instrument capable of accurate and dependable measurement of dosage from gamma rays, betas, protons, and neutrons. The detectors are configured so that the dose from a selected radiation type can be isolated from other types of radiation. Electronics and software have been developed to perform real time acquisition of spectral data for protons, electrons and photons, and integrated dose data for neutrons. Software algorithms are used to analyze this data and determine the dose from each type of radiation. A compact, battery powered, prototype dosimeter, employing the new detectors, electronics, and special software algorithms, is now being fabricated for testing by the Air Force.

This research was performed by Dr. Gerald Entine of Radiation Monitoring Devices, Inc.; (617) 926-1167. The contract was administered by Kenneth A. Hardy, Human Systems Division at Brooks AFB; (512) 255-5616. ■

Development of a Pulsed 1.06-Micron Solid-State Coherent Laser Radar for Wind Velocity and Aerosol Backscatter Measurements

The rapidly developing solid-state laser technology has several promising advantages including efficiency, compactness, and a long lifetime. For these reasons a compact laser radar (lidar) system would be ideal for. 1) surveillance for wind shear and aircraft trailing vortices, 2) wind profilers for the meteorological community, and 3) on board airliner warning system for turbulence, enroute winds, and wind shear.

Solid-state coherent operation at eyesafe wavelengths and total diode-laser pumping is now feasible. Presently a coherent lidar system is in development. It utilizes solid state Nd:YAG lasers operating at 1.064 microns. Designed for measurements of atmospheric wind velocity and aerosol backscatter, the performance of this lidar system, when used for atmospheric wind velocity measurements, anticipates a velocity resolution of better than 1 m/s. This range resolution is less than 200 m and has a pulse repetition frequency of 0.1 to 5 Hz.

The master/local oscillator used in the lidar is a continuous-wave (CW) laser-diode-pumped single-longitudinal-mode Nd:YAG laser. It utilizes a linear cavity with a brewster polarizer and two quarterwave plates internal to the laser cavity. The quarterwave plates, which are placed on each side of the Nd:YAG rod, are used to eliminate spatial hole burning in the Nd:YAG material. Initial measurements show that the master oscillator produces 30 mW of power in a single longitudinal mode when pumped by a 200 mW laser diode array. The short term (<1 sec) frequency stability is less than the 2 MHz resolution of the optical spectrum analyzer.

When used in the lidar system, the output of the master oscillator is first passed through a Faraday isolator. Next a portion of the output is split off, focused onto, and collected by a polarization-preserving, single-mode optical fiber. This portion served as the local oscillator beam. The remainder of the output is gated and frequency shifted by an acousto optic modulator operating at a center frequency of 200 MHz. These output remains are magnified by a pulsed, high-gain, multi pass, flashing pumped slab amplifier.

The output of the amplifier, whose pulse repetition frequencies measure up to 10 Hz, is incident upon an off-axis Dall-Kirkham telescope. This telescope transmits the pulse onto the atmosphere. Backscattered radiation from the atmosphere is collected by the 20 cm diameter telescope, focused onto and collected by a polarization-preserving, single-mode optical fiber, and combined with the local oscillator beam in a fiber coupler. The heterodyne signal is then detected and processed by an I-Q complex receiver. The I and Q outputs from the complex receiver are digitized and transferred to a digital computer where the raw data is processed to extract Doppler velocity and backscatter information. The data acquisition system utilizes a DEC MicroVAX II computer, a LeCroy 9400 digital oscilloscope, and a Pericom MX 2000 color graphics terminal. The output is observed in real time or archived for later analyses. Figure 1 shows the solid-state lidar system in the laboratory. The lidar has been used to measure the velocity of calibrated known velocity targets such as spinning discs and belt sanders. Currently, atmospheric testing is also being conducted.

This research was performed by Dr. Michael J. Kavaya of Coherent Technologies, Inc., (303) 449-8736. The contract was administered by Lt. Sylvia E. Ferry, Air Force Space Technology Center, WCO at Los Angeles AFB, (213) 643-1005. ■

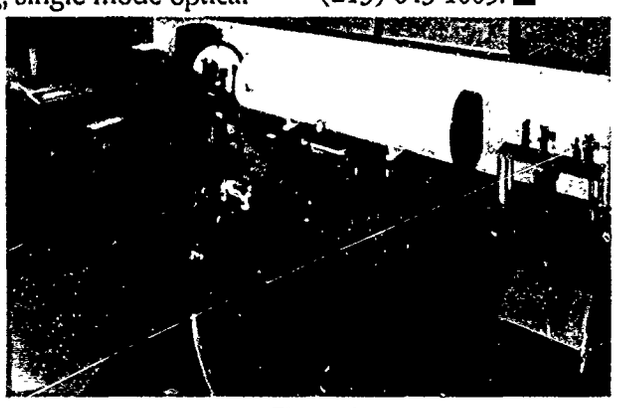


Figure 1
Pulsed Coherent Solid-State 1.06-Micron Laser Radar

Voltage Measurement Instrument for Gallium Arsenide Integrated Circuits

The need for a voltage measurement instrument based upon electro-optic sampling for gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs) arose from research by Bloom and colleagues at Stanford University. They discovered that the electro-optic property of GaAs allowed optical voltage measurements directly in the GaAs substrate. Most high speed integrated circuits (ICs) made today use GaAs as the substrate.

In Phase II of this project, the primary objective was to develop a voltage measurement instrument (taking into consideration the Stanford University results), which allowed non invasive probing of MMICs, much the way an oscilloscope and voltage probe accept measurements of low frequency circuits. Secondary objectives were to work with various MMICs to improve measurement techniques and to determine the usefulness of the measurements to the GaAs MMIC engineer.

The basic concept behind the instrument design is a change in the refractive index of a crystal produced by an electric field called the linear electro-optic effect. Gallium arsenide is electro optic, and electric fields cause its index of refraction to change slightly. This results in a rotation of the polarization of an optical beam passing through it. For the typical GaAs IC substrate crystal orientation, the amount of rotation is a function of the magnitude of the voltage applied across the substrate. If the applied voltage is a result of a microwave MMIC signal, it can be measured non invasively. This is done by measuring the amount of polarization rotation of an infrared beam passing through the substrate.

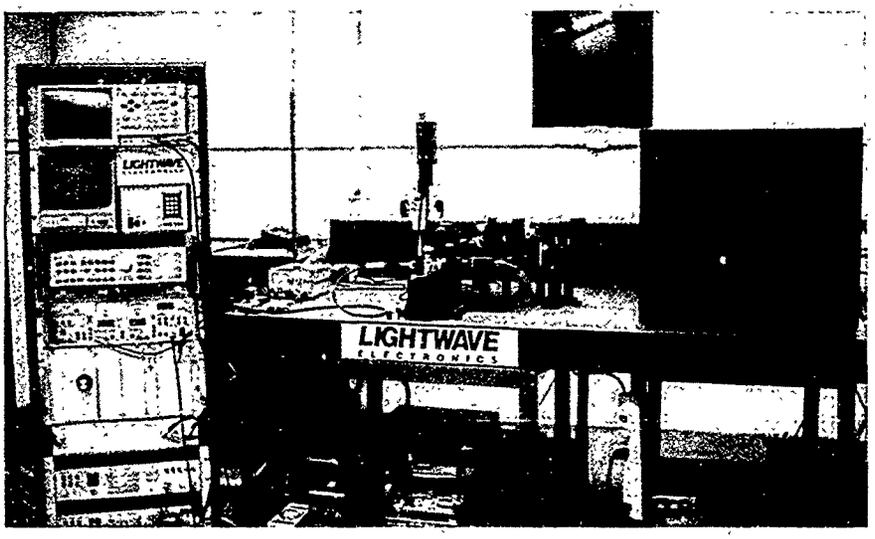


Figure 1
Voltage Measurement Instrument for GaAs Integrated Circuits

To obtain very high measurement bandwidths, exceeding 100 GHz, sampling techniques are used. The laser operates in a pulsed condition called mode-locked, producing a train of very short light pulses. These short pulses then precisely strobe out the microwave voltage waveform. In effect it slows down the signal and allows use of readily available slow photodetectors.

Figure 1 shows a block diagram of an electro optic sampling system. The laser produces a train of 90 picosecond (ps) long pulses repeating at an 80 MHz rate. The 90 ps long pulses are then reduced to 1.5 ps with a fiber-grating pulse compressor. The pulses are phase locked to a microwave synthesized source by an electronic phase lock-loop feedback system. This system reduces timing jitter between the laser and the synthesizer to less than 0.5 ps. With the compressed, jitter-stabilized pulses, a system bandwidth greater than 100 GHz is achieved.

This optical beam is focused into the GaAs substrate, where it senses the microwave line voltage through the electro-optic effect. Figure 2 shows the frontside probing geometry typically used for MMICs. The beam is reflected off the back side groundplate and returned to the detector. For coplanar geometry, which was used for digital GaAs devices, the beam is brought in through the backside and reflected off a front side metallized trace. The reflected light is directed through a polarizing beamsplitter onto a photodetector, where changes in intensity occur in proportion to the voltage on the GaAs circuit. One condition required to do optical probing is a polished and coated backside to reflect the laser signal back to the detector. From work with industry during the Phase II project, it was determined that a two-step backside thinning process, where the second step

uses a mechanical-chemical etch such as bromine-methanol, results in polished backside well-suited for optical probing.

The optical probing beam is moved in X & Y axis direction under computer control to measurement points in the circuit. An infrared TV camera and monitor allow the user to position the sampling point on the circuit. To drive the IC, the microwave synthesizer generates sinusoidal excitation. For measurements at the wafer level, microwave wafer probes are used to deliver 0-20 GHz signals. To enhance the system sensitivity, the drive signal is pulse modulated at about 1 MHz to allow synchronous, narrowband detection away from low-frequency laser amplitude noise. Sensitivity of better than 100 μV per root Hz is achieved.

Using a personal computer, software was written to control the X-Y beam scanning hardware, the data acquisition process, and the system. It allowed for voltage measurements at different points on the circuit and stored the results for later analysis. Voltage calibration routines and specialized software continue to be developed as actual measurement experience is gained.

The key measurement capabilities of the Lightwave electro-optic sampling proved to be:

- Non-invasive
- Internal mode and input/output probing
- Spatial resolution of 5 to 10 minutes
- Time resolution of <2 ps or a bandwidth 100 GHz
- <100 microvolt sensitivity

Figure 3 shows an optically measured waveform from a C-band power amplifier. The distorted waveform was on the internal node at the output of the second stage of the amplifier. This is where significant harmonic distortion is expected and observed. The output waveform, measured next to the output bonding pad, is cleaned up considerably after passing through the output matching network, which filters unwanted distortion. Circuit measurements to 20 GHz have been made on the system.

Based on results in the industry, this prototype instrument is being used to test circuits developed in the MIMIC (microwave/millimeter wave monolithic integrated circuits) program. Additionally, the timing stabilizer phase-lock-loop has been developed into a commercial system. This system reduces the pulse-to-pulse timing jitter on mode-locked lasers from about 10 ps to less than 1 ps. The stabilizer allows precise synchronization of these lasers to electronic signal sources such as microwave synthesizers.

Key to the commercial success

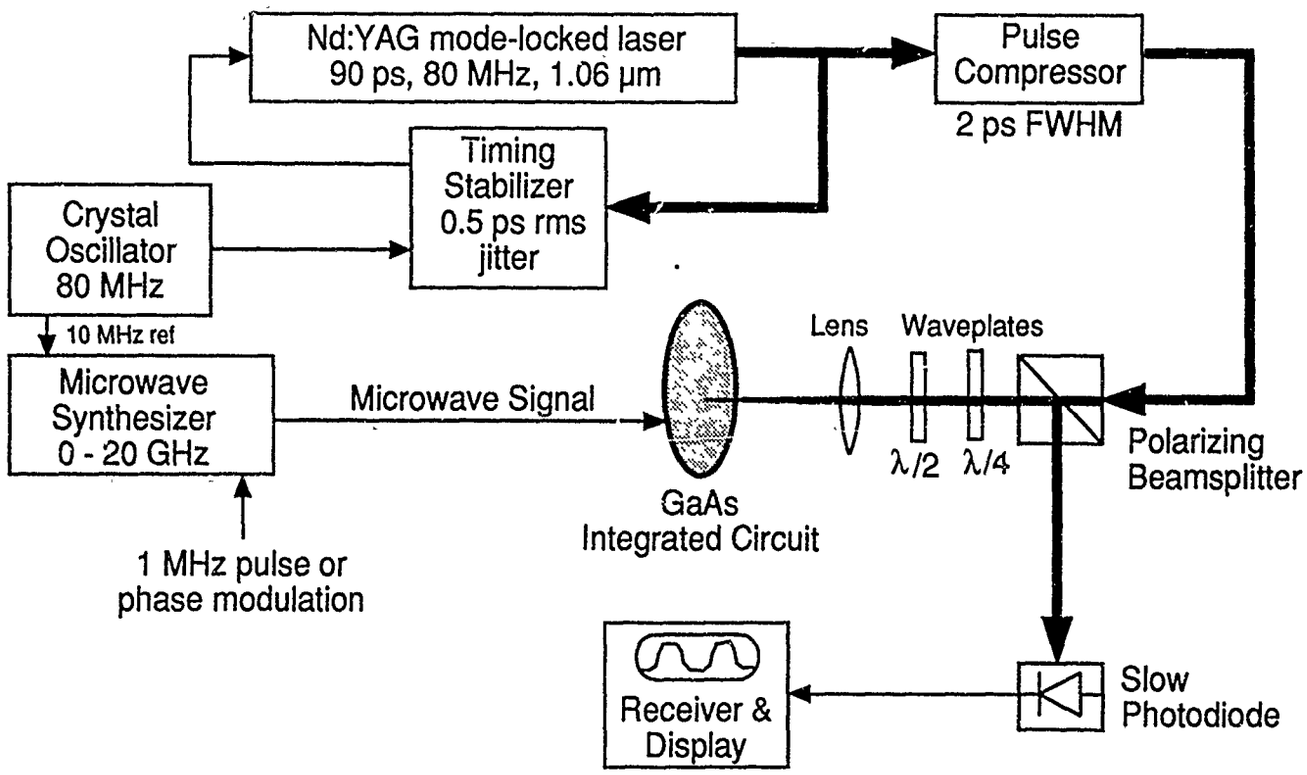


Figure 2
Block Diagram of Electro-optic Sampling System

of the voltage measurement instrument is an improved picosecond laser source. Currently, a lower-cost, higher-performance laser-diode-pumped solid-state laser optimized for electro-optic sampling is being developed to replace the conventional flashlamp-pumped commercial laser used in this research.

This research was performed by Dr. Richard Wallace of Lightwave Electronics; (415) 962-0755. The contract was administered by Thomas A. McEwen, Rome Air Development Center at Griffiss AFB; (315) 330-4381. ■

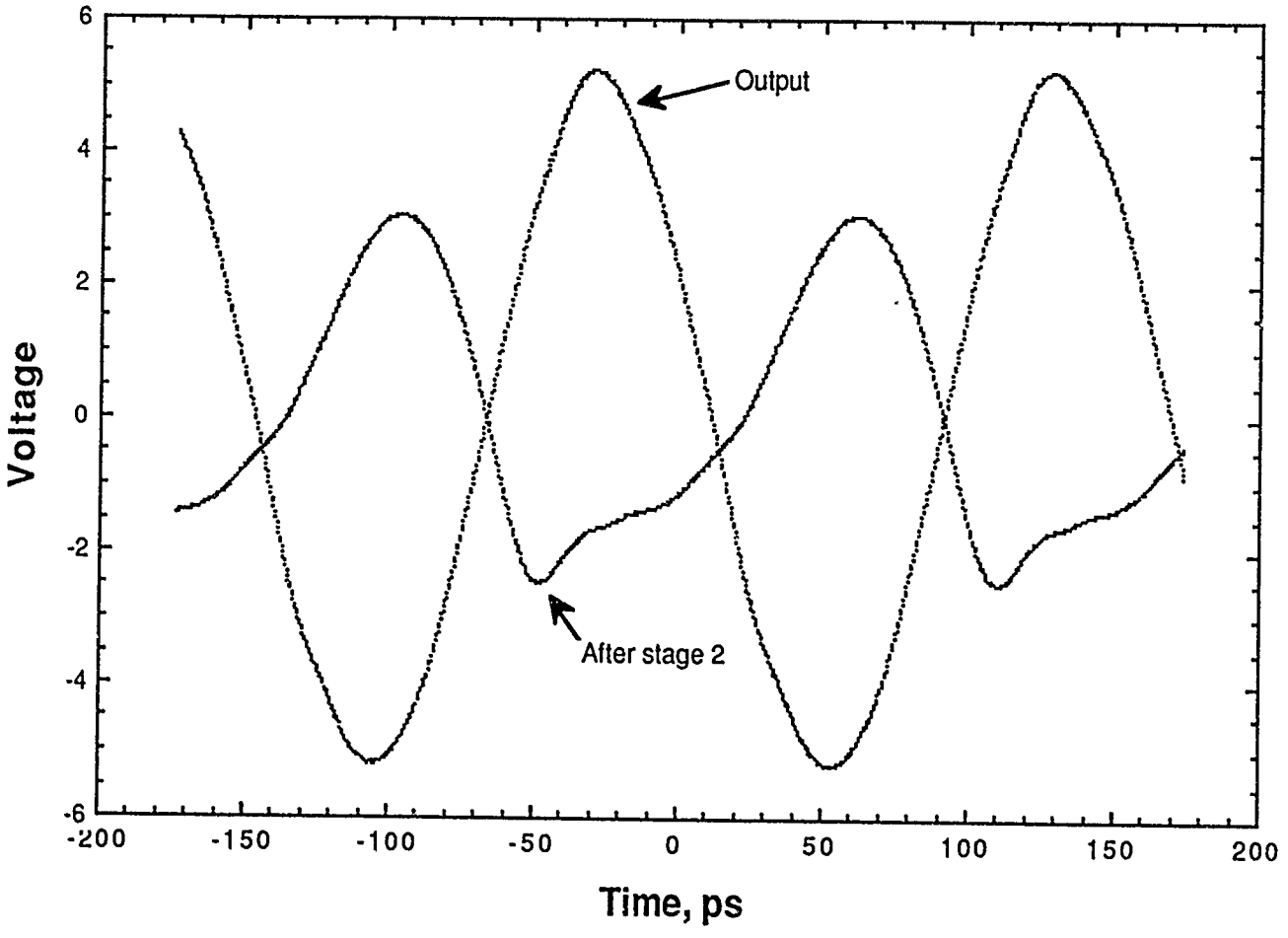


Figure 3
Optically Measured Waveforms

Hydraulic Excavation System Development

Trying to overcome the limitations associated with the use of explosive or tunnel boring machines led to the research for developing new techniques of excavating hard rock. Explosives are an efficient way of excavating hard rock; however, conventional drill and blast methods may pose a hazard to nearby facilities or personnel through fly rock, dust generation, excessive ground motion, and release of toxic fumes. Blasting is thus limited to remote tunnels and mines where these factors are less important. Blasting also introduces significant damage to the walls of a tunnel so that a concrete liner must often be placed to prevent rockfall.

Another rapid excavation technique uses tunnel boring machines (TBMs). These are large, expensive machines requiring significant time for site preparation, assembly, and breakdown. They provide cost-effective non-explosive excavation of long tunnels where the high capital cost and long setup/breakdown times are offset by the advantages of continuous tunneling and a smooth circular tunnel profile which often requires no liner. TBMs are inappropriate in short tunnels or in situations where a non-circular or non-straight geometry is required.

The hydraulic excavation (HYDREX) system, which is shown in figure 1, is capable of non-explosive excavation of hard rock in any geometry required. The project was initiated with a theoretical study which demonstrated that a simple hydraulic system could induce multiple fracturing and fragmentation in hard rock. These results were verified by laboratory tests carried out during Phase I of the project. In Phase II, a prototype excavation system was tested in a field excavation. These test results have led to the design of a commercial excavation system with a wide range of applications.

The HYDREX system is based on a theory of dynamic rock fracture mechanics. It predicts that a sufficiently rapid pressure pulse in a borehole will result in multiple fracturing of the surrounding rock. A series of tests carried out at Sandia National Laboratories showed the effect of pressurization rate on the transition from hydraulic fracturing to multiple fracturing to explosive rock fragmentation. In conventional blasting, rapid pressure pulses were produced by chemical explosives. In the Phase I work it was determined that similar pulses could be produced by discharging a water-filled accumulator into a cavity. The accumulator was charged with water at a pressure of 60,000 psi which was sufficient to cause significant compression and energy storage. In the initial feasibility study, the accumulator was discharged through a rupture disk. The pressures developed by this device were capable of fragmenting hard, volcanic rock.

The objective of the Phase II project was to develop the HYDREX concept into a practical excavation system. The first task was to develop a quick opening discharge valve for the HYDREX tool, because the use of rupture disks was considered impractical. This work resulted in a poppet valve design with discharge characteristics superior to the burst disk. The wave allows the tool to be repeatedly discharged, thus greatly improving productivity. The prototype HYDREX tool developed in Phase II delivers a hydraulic impact comparable to the most powerful impact hammers available.

Since the HYDREX tool is discharged into a small-diameter borehole, it is necessary to integrate a drilling mechanism into the excavation system. A waterjet-assisted drill was used on the prototype system. These drills have very low torque and thrust requirements. This greatly facilitated design integration into the prototype excavation system. Jet-assist power for the drill was provided by the same 55,000 psi pump that powers the HYDREX tool.

The HYDREX tool and jet-assisted drill were mounted on turret assembly. Then it was indexed to the drill mechanism to ensure quick tool insertion. Hydraulic actuators on the turret provide for extension of the tool and drill, horizontal yaw motion, and extension of a sting to securely locate the assembly on the rock face. The entire assembly was mounted on a backhoe arm for tool positioning.

The Phase I research demonstrated that the pressures developed by the HYDREX tool were sufficient to fragment hard volcanic rock. These tests were carried out on large, unconfined boulders of Andesite. Unconfined rock was relatively easy to fragment, because there was nothing to stop the fragments from rotating and moving apart. In a confined rock face, fracturing was not always accompanied by fragmentation, since rock segments often remain keyed in place.

In Phase II development work, large blocks of reinforced concrete

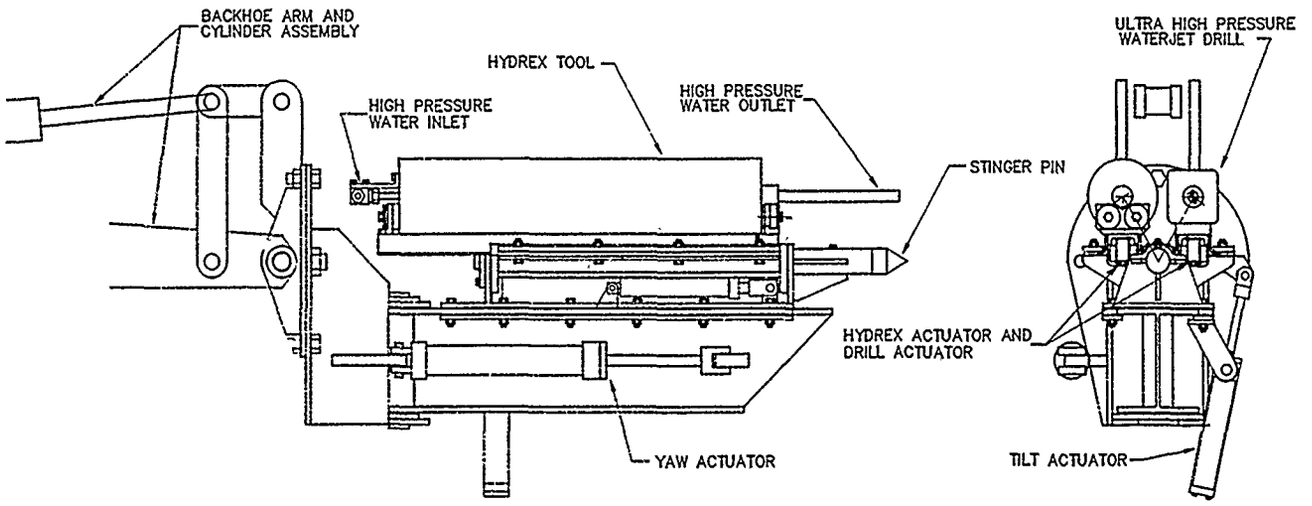


Figure 1
HYDREX System Assembly

were prepared to simulate a confined rock face. Excavation of these blocks was carried out with the prototype HYDREX excavation system to evaluate fragmentation and productivity in confined material. The specific energy required for excavation of the concrete was measured and found to be similar to that of conventional drill and blast techniques. However, the energy was substantially lower than required by a tunnel boring machine.

In addition to being relatively efficient, a practical excavation system must be extremely reliable. During testing in concrete, the prototype HYDREX tool was fired over 1000 times without wear of critical valve parts.

Field testing of the prototype HYDREX system was carried out in a hard volcanic rock quarry. The system was used to excavate a horseshoe shaped tunnel, opening into an Andesite face. This material was found to have a compressive strength of 20,000 to 40,000 psi. Excavation productivity and efficiency were measured by timing the excavation steps and weighing the material removed. These tests demonstrated the system capability by excavating 20,000 pounds of rock in 20 hours. Most of the work involved was devoted to removing fragmented rock and tool positioning. Mechanization of the mucking process and simplified tool positioning will improve productivity to over 25 cubic yards of hard rock per day.

The HYDREX project resulted in the development of a practical hydraulic excavation system with a variety of applications. The capital cost of the equipment is low compared to tunnel boring machines, and the system may be quickly deployed to meet the needs of a complex tunneling or construction project. Air Force applications for the HYDREX system include construction or expansion of hardened ballistic missile launch sites and command centers. The greatest application will be for moderate size openings where conventional blasting is not an option and tunnel boring machines are too expensive. The flexibility of the HYDREX system will greatly reduce the cost of moderate sized facilities in hard rock, thereby expanding the range of options available to Air Force planners.

A number of commercial applications for the HYDREX tool have also been identified. These include deep level non-explosive mining, urban construction, concrete demolition, and boulder fragmentation. The use of this flexible, non explosive excavation system will substantially reduce the cost of these types of projects.

A highly specialized application of the HYDREX tool has already been realized. A modified version of the tool is now being tested by the operator of the Three Mile Island nuclear power plant as a means of fragmenting the melt products pooled in the bottom of the reactor vessel. Fragmentation tests on hard materials thought to characterize this material have been highly successful.

This research was performed by Dr. Jack Kolle of Flow Research, Inc., (206) 872 8500. The contract was administered by Lt. Andrew Ghali, Ballistic Systems Division/MYEB at Norton Air Force Base; (714) 382 2592. ■

The Development of a New Chart for Testing Vision: Suprathreshold Contrast Sensitivity

Visual acuity, used for 126 years to evaluate vision, is a measure of the eye's ability to focus on different images. The idea that "20/20" always means good vision originated with the acceptance of the standard Snellen or "E" chart in 1862 and the development of military vision standards in 1912. However, visual acuity does not relate well to everyday visual tasks such as seeing objects of different sizes and contrasts when driving in fog or rain. Snellen acuity is also unable to detect certain eye disorders. In many instances, people with eye disease can still score 20/20 on a Snellen chart.

Contrast sensitivity, the ability to discern subtle changes in shades of gray, has emerged as a more comprehensive way to describe vision. In addition to measuring the eye's focusing ability, contrast sensitivity evaluates the quality of contrast perception at the retina/brain system level, the next stage of vision information processing. Images in the retina/brain system are converted to neural codes that are based primarily on the shape and contrast of an image. This approached is based upon a multi channel model of the visual system in which sets of independently operating cells are each tuned to different ranges of image sizes. These sets of cells, called channels, are considered to play a major role in the "filtering" of relevant image information such as size, shape, and contrast.

Sine-wave gratings, shown in figure 1, are used as visual targets for contrast sensitivity testing, because they can represent any size, shape, or contrast of an image. A sine-wave grating is a repeated sequence of light and dark bars whose luminance profiles vary sinusoidally about a mean luminance with distance. Gratings with higher spatial frequencies correspond to smaller objects, while gratings with lower spatial frequencies correspond to larger objects.

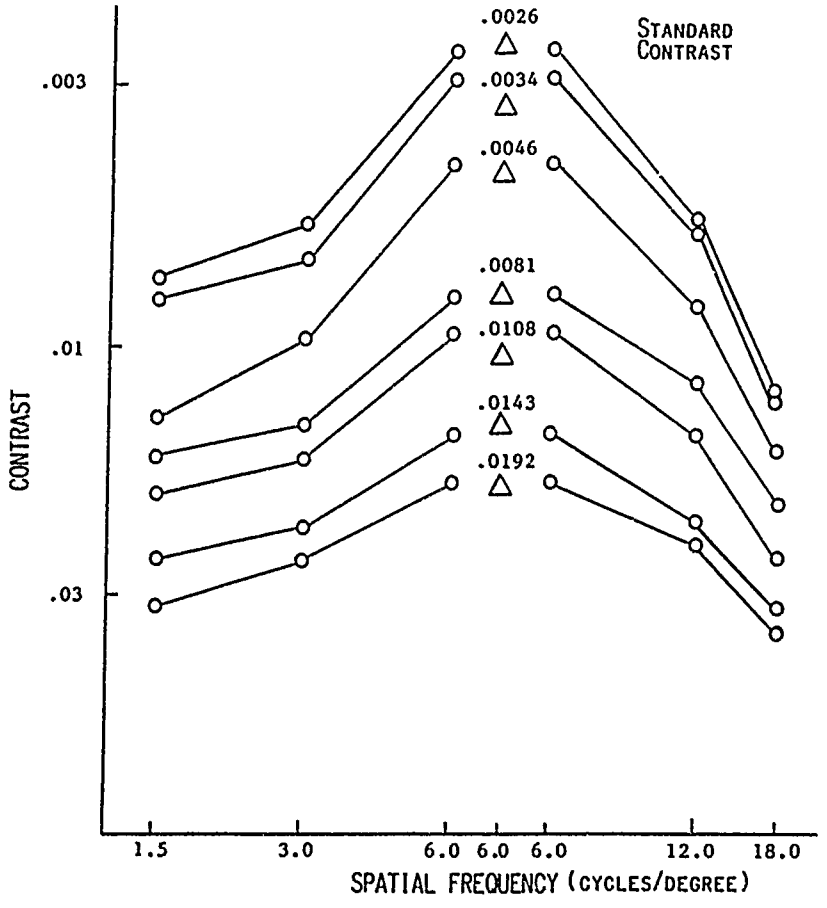


Figure 1
Examples of Sine-Wave Gratings

Contrast sensitivity is typically measured at threshold levels, i.e. the minimum amounts of contrast necessary for an observer to detect sine-wave gratings. Quick, simple, and inexpensive techniques for measuring threshold contrast sensitivity have existed for several years. Although these tests have proven useful for a variety of purposes, most visual perception occurs at suprathreshold levels of contrast. A contrast suprathreshold for a sine-wave grating is any level of contrast above the threshold level. Vision scientists have developed techniques for measuring suprathreshold contrast perception such as magnitude estimation and contrast matching as illustrated in figure 2. Because these techniques involve video-based computer systems that are time-consuming and expensive, the need arose to develop a vision chart that could measure contrast suprathresholds in a quick and inexpensive manner.

A psychophysically rigorous contrast-matching suprathreshold

vision chart configuration was designed and developed. Using the new chart configuration, a family of suprathreshold contrast sensitivity curves were obtained by testing a group of subjects. These curves are similar to those obtained with the video-monitor systems previously required for this type of testing. The average curves for suprathreshold contrast perception plotted against spatial frequency appear in figure 3. As expected, individual differences in suprathreshold contrast perception were found. The data suggest that these differences were due to real differences in contrast perception ability and not criterion, and imply that the individual differences measured by this chart may be relevant for predicting visual task performance.

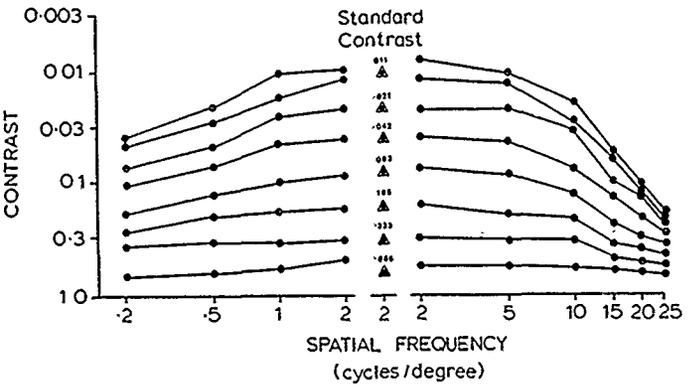


Figure 2
Contrast Sensitivity Curves Obtained With Computer-Video Syst·

Suprathreshold contrast perception may be especially relevant to four major Air Force needs: 1) the understanding of how a pilot's contrast perception relates to his or her visual performance, 2) the development of a suprathreshold model of perception; 3) the understanding of how visual channels behave at suprathreshold levels of contrast, and 4) the detection of ocular pathologies. With threshold contrast sensitivity emerging as a major metric for performance-related vision standards, an understanding of the measurement of suprathreshold contrast perception will also be important. The suprathreshold contrast chart will be an ideal tool to obtain large populations of pilot data.

A further understanding of suprathreshold contrast perception is needed not only for computer simulated vision models, but also to better understand the process of matching the observer's characteristic visual processing capability to displayed and simulated imagery. For example, just as contrast sensitivity functions are important to understanding certain aspects of displayed imagery, such as target bandwidth requirements and evaluation of heads-up displays, so, too, will suprathreshold contrast perception help evaluate other aspects of displayed imagery such as the number of contrast levels required for effective target imaging.

The new suprathreshold chart will allow information to be gathered on how visual channels behave at suprathreshold contrast levels. Many unanswered questions remain about the linearity of suprathreshold contrast perception and how the gain mechanisms behave at suprathreshold levels.

Tremendous clinical applications to individuals and organizations other than the Air Force also exist for this new chart. Certain contrast matching studies, for example, have shown that each eye for amblyopes may vary by as much as 10-15 decibels. Other pathologies may also be indicated by similar abnormalities in suprathreshold contrast matching performance.

This research was performed by Dr. Arthur P. Ginsburg of Vistech Consultants, Inc.; (513) 426-4822. The contract was administered by Dr. John Tangney, Air Force Office of Scientific Research at Bolling AFB; (202) 767-4278. ■

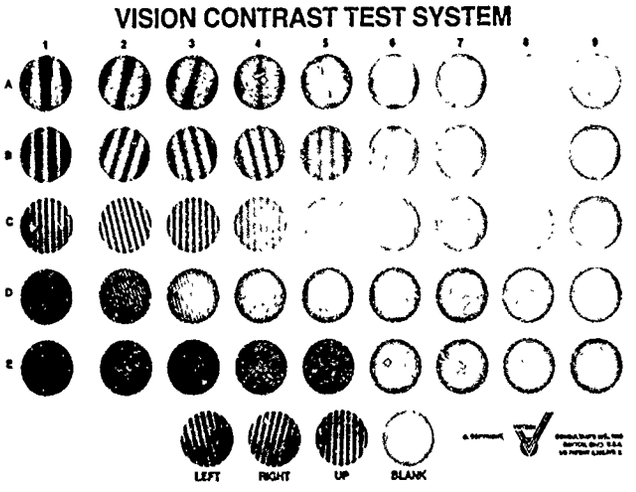


Figure 3
Contrast Sensitivity Curves Obtained With New Suprathreshold Vision Test Chart

Material Corrosion Inspection by Dual-Energy Radiography

Corrosion of equipment and material is a ubiquitous problem. For the Armed Forces, preventing, detecting, and repairing corrosion is a crucial part of their continuous struggle to keep military systems in full combat readiness. This project developed a preprototype dual-energy x-ray scanner to be used for corrosion detection and demonstrated its effectiveness and utility. Dual-energy radiography has the ability to give detailed internal material property information of material structures.

The term "dual-energy" is utilized in this context to indicate that as a standard part of the inspection procedure, radiographs are taken at two different effective energies. It is implicitly assumed that the radiographs are digital at some point in the processing. This way they may be analyzed to provide additional information not otherwise available with conventional (single-energy) radiographic systems. In the x-ray energy ranges used for most radiographic systems, x-ray scattering (or absorption) can be explained by three interactions—photoelectric, Compton, and pair-production. At relatively low energies (below one million electron-volts), Compton and photoelectric effects dominate. Meanwhile at higher energies (above one million electron-volts), Compton and pair-production effects dominate. No more than two interactions need to be considered at one time to account for the absorption of x-rays in matter when dealing with radiography. Digital radiographs obtained at two different energies can therefore be readily analyzed.

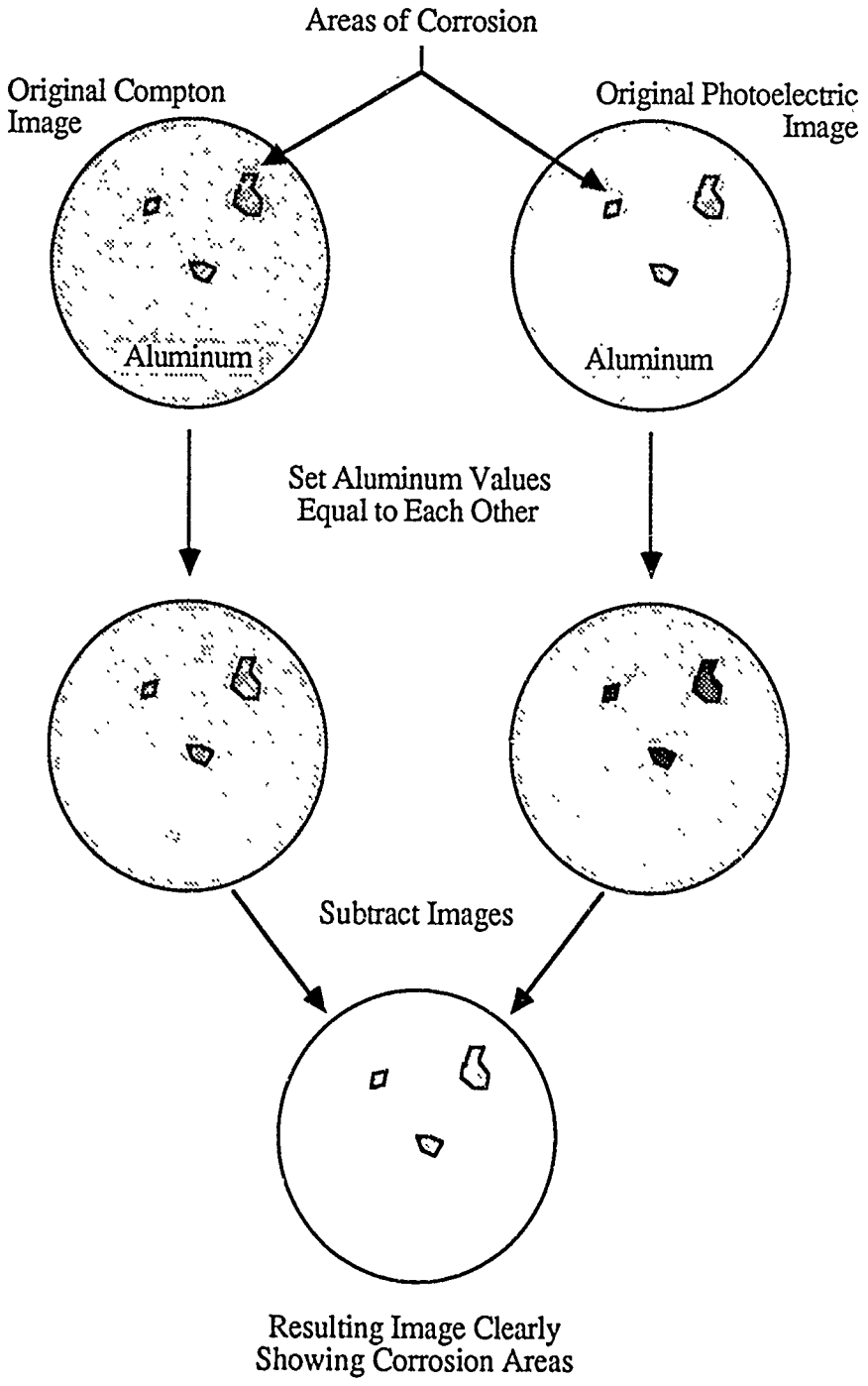


Figure 1
Dual-Energy Image Subtraction Process

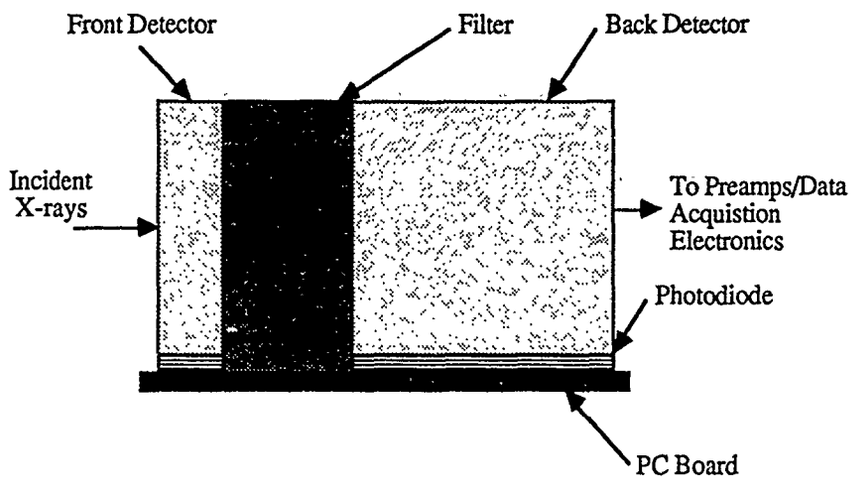


Figure 2
Dual In-line Detector

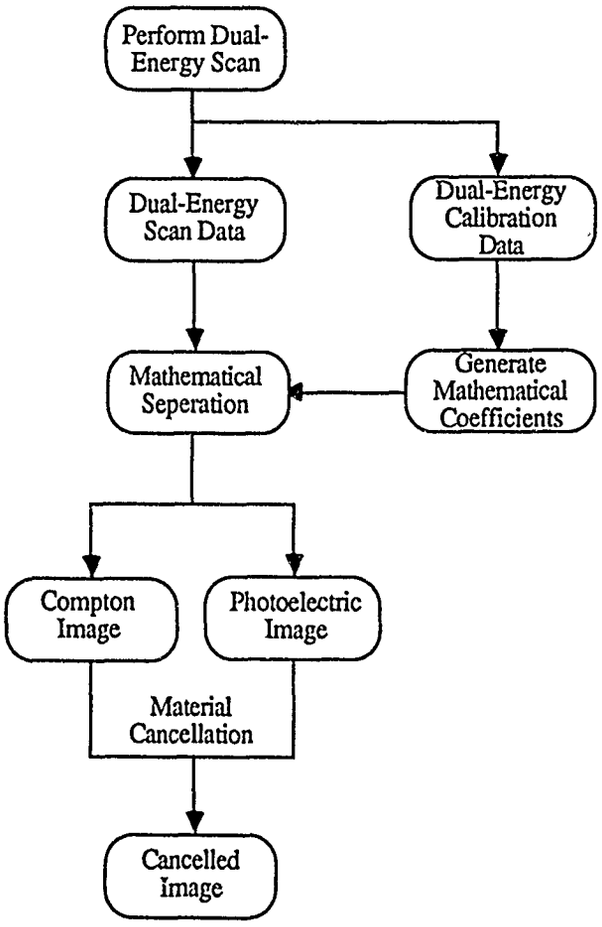


Figure 3
Dual-Energy Formulation Procedure

The results show the individual contributions of the competing interactions to the total attenuation.

This process, carried out by algebraically processing two radiographs taken at different x ray source energies, resulted in a pair of new images: one referred to as the "Compton image" and the other as the "photoelectric image" Since these images depend in known ways on density and atomic number, they provide a powerful handle for determining the fundamental physical properties of the material under examination. A particularly powerful use of this technique is to "cancel" the predominant material in the image to improve the conspicuity of other materials that may be present. This is accomplished by performing a weighted subtraction of the "Compton image" from the "photoelectric image". Only one element (or compound) at a time can be cancelled in this manner. The dual-energy cancellation procedure is illustrated in figure 1.

The power of this technique lies in the fact that it allows the user to identify different materials in the object under examination. For instance, if an aircraft structure was composed largely of aluminum, then the aluminum could be cancelled and the residual image studied. As a result, only non-aluminum material would be present in the residual image. Normally expected items, such as fasteners, gaskets, sealants, etc., would be readily recognized by the inspector; and any corrosion or other foreign matter, if it existed, would be visible as anomalous patches of unexpected material. Since non-aluminum items were generally well known and well specified, and those areas most likely to corrode were presumably well-defined, it should

be a straightforward task to search for the presence of corrosion in susceptible components. This technique might also turn out to offer a rapid way to screen for mission components, such as critical washers or gaskets, since the conspicuity of small parts is greatly increased when more dominant materials are cancelled in a radiograph.

The objective of this program was to design and build a preprototype dual energy scanner to demonstrate this principle. The basis for the design was current x ray scanning equipment with necessary modifications to make the system applicable to dual-energy radiography. The important modifications were the x-ray detector design and the software configuration.

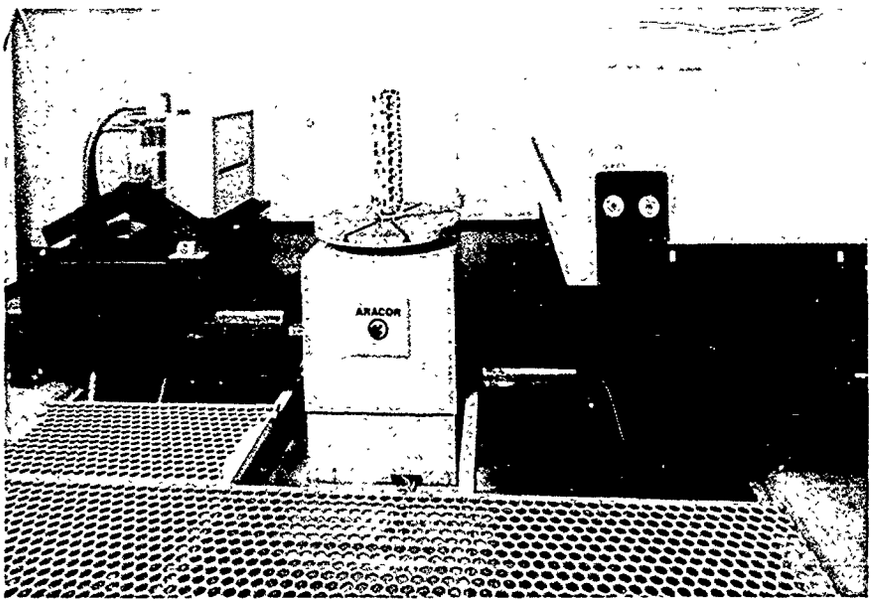


Figure 4
Dual-Energy Scanner

For this scanning system, x-rays were aimed through a part (i.e., washers, gaskets) and the x-rays that penetrated the part were measured by a set of x-ray detectors. Denser materials absorbed more x rays, so naturally they corresponded to lower detector readings. The x-ray detectors "glow" when exposed to the x rays. This "glow" was picked up by photodiodes, which con verted the light to an electrical signal. The greater the number of x rays impinging on a detector, the greater the "glow" was, and hence, the greater the electrical signal. The magnitude of the electrical signal was digitized and stored in a computer for future processing.

One method for obtaining dual energy radiographs was to take digital radiographs of an object at two different x ray energies. Another method, which was the one employed here, was to have two sets of x-ray detectors. One set was sensitive to low x ray radiation energies and the other set was sensitive to higher x ray radiation energies. Most industrial x ray sources simultaneously send out a range of x-ray energies rather than generating a single energy. The dual in-line detector design allowed the acquisition of a complete dual-energy data set with a single exposure. This cut the scan time in half when compared to the two energy exposure approach. Figure 2 shows a schematic of the dual in-line detector. The front detector senses the low energy x-rays and transmits the reading to the photodiode. A filter further "weeds out" the low energy x rays so that the second detector can efficiently measure the higher energy x rays and transmits these values to a separate photodiode.

The software task consisted of developing the necessary computer codes to process the dual energy data. The dual-energy technique included acquiring and processing the readings from the two arrays of dual in-line detectors. Dual energy calibration data was obtained by scanning an object of known thickness and composition. The calibration data was used to determine the mathematical coefficients necessary to separate the dual-energy data. Component images were then used to cancel a given material and view the corrosion, as for example, in an aluminum part. The mathematical formulations and the corresponding computer codes necessary to carry out this process were developed as part of this program. A flowchart of the dual-energy formulation procedures is shown in figure 3.

The result of this project was a fully integrated dual-energy scan system as shown in figure 4. The photograph shows the x-ray source on the left, the circular table for positioning the objects to be scanned in the middle, and the detector package and electronics on the right. The operation of the scanner is controlled remotely by a computer system. The operator has a computer terminal screen, a keyboard to type in commands, and a color display monitor for image presentation.

To demonstrate the capability of dual energy radiography, a dual-

energy scan was performed on an aluminum antenna panel that had corroded in certain areas. Dual-energy radiographs of the antenna panel were taken and processed. The resulting "Compton image" and "photoelectric image" are shown in figure 5. The aluminum was then effectively "cancelled" from the images to highlight any areas containing non-aluminum material such as corrosion. Two effective atomic numbers (Z) were used to cancel the aluminum, since the aluminum was an alloy and not a pure material.

The application of dual-energy radiography to corrosion detection is an important step forward in minimizing the detrimental effects of corrosion in military equipment. Early detection of corrosion minimizes its damage by allowing for more economical repairs and safer equipment operations. Dual-energy radiography, however, can be applied to a wide variety of inspection needs because of its ability to accurately determine density and atomic number differences in materials. This can greatly improve current non-destructive inspection techniques and provide information that can not only enhance defect and contamination detection, but also augment understanding of how damage and contamination grow and progress.

This research was performed by James H. Stanley of Aracor; (408) 733-7780. The contract was administered by Thomas Moran, Wright Research Development Center/MLLP at Wright-Patterson AFB; (513) 255-9806. ■

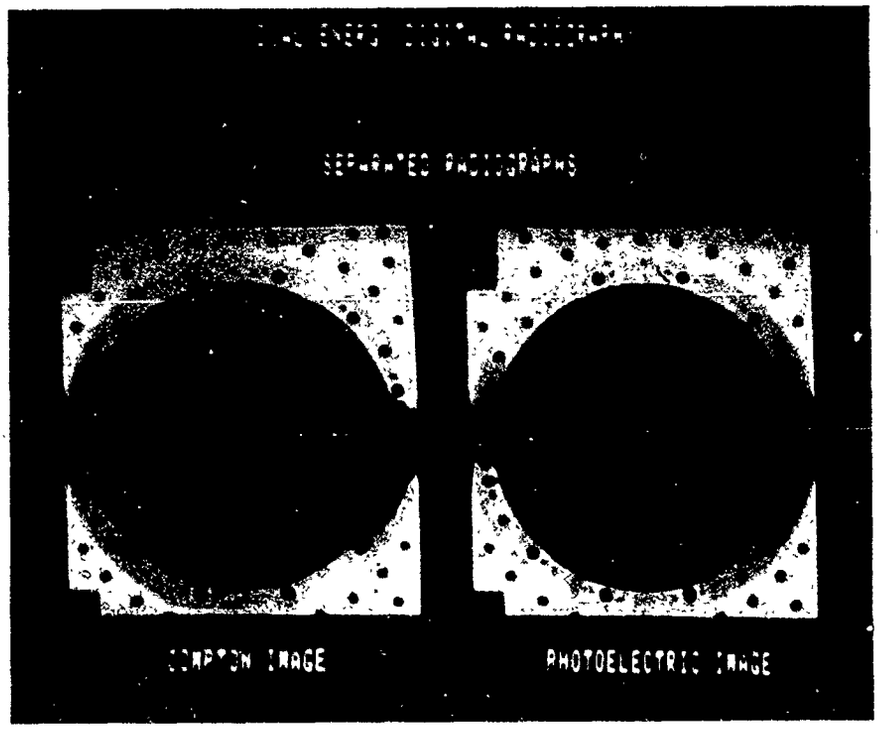


Figure 5
Compton and Photoelectric Images of Antenna Panel

High Temperature Heat Pipes for Semiconductor Crystal Growth

Crystal growth is temperature sensitive. A semiconductor crystal will grow more rapidly in any part of its environment that is cooler than the rest. Crystal growers can enhance uniformity, and minimize defects, by providing a constant-temperature (isothermal) environment. This applies both to bulk crystal growth (in Czochralski furnaces) and to layered (epitaxial) crystal growth.

In heat pipes, a working fluid was boiled at one end and condensed at the other. The condensing end was inherently isothermal, because the vaporized working fluid naturally flowed to, and condensed on, any portion of the surface that might be the least bit cooler than the rest. This resulted in the cooler surface heating up.

Heat pipes also transfer plenty of heat. The working fluid within a heat pipe can transfer much more heat via the heat of vaporization than could any metal via conduction. At high temperatures, much of the heat transferred to the heat pipe is lost to thermal radiation. This feature of heat pipes becomes essential.

Heat pipes can be made in almost any geometry. To minimize the circumferential temperature variations that plague Czochralski growth, toroidally shaped heat pipes can surround the crucible inside which the crystal is pulled from the melt, as shown in figure 1. In epitaxial growth, one can maintain the substrate (the flat piece of semiconductor onto which the crystal layers are to be grown) at a constant temperature by placing it on a heat pipe with a flat condensing section, as shown in figure 2.

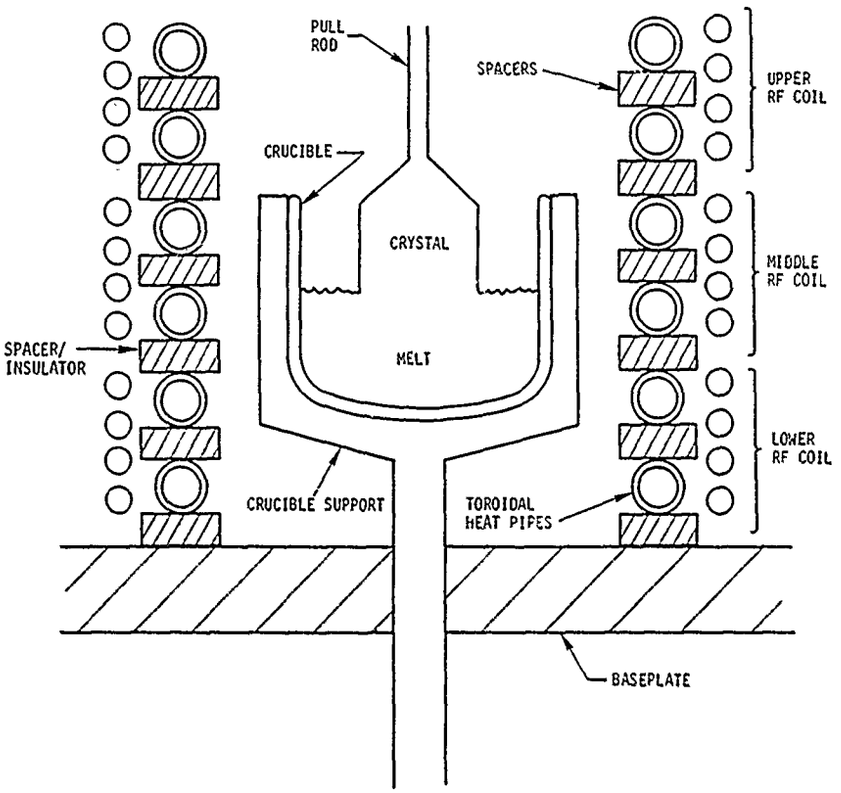


Figure 1
Toroidal Heat Pipes Surrounding Crucible

In both cases, heat was transferred to the casing of the heat pipe by RF induction. Figures 1 and 2 show the cross-sections of RF coils made of water-cooled copper tubing. The toroidal heat pipe (figure 1) receives suscept RF energy on its outer surface facing the RF coil, and boils the working fluid on the corresponding inner surface. The working fluid condenses on the opposite inner surface (nearest the crucible) and the corresponding outer surface radiates heat to the crucible. The flashlight-shaped heat pipe (figure 2) suscepts RF energy with its lower "stem," inside which the working fluid boils. The working fluid condenses in the upper portion, which conducts and radiates heat to the substrate.

Working fluids for these configurations can be selected primarily for their pressure-temperature characteristics. The toroidal heat pipe used to heat a Czochralski furnace must operate at 1250°C. Magnesium was used as its working fluid, because the vapor pressure of magnesium at that temperature is roughly one atmosphere. The flashlight-shaped heat pipe used for epitaxial growth must operate around 700°C. Potassium was used as its working fluid, because the vapor pressure of potassium at that temperature is roughly one-half atmosphere.

The structural material used to contain the working fluid and transfer heat must be able to withstand operating temperatures. It must also be formable, machinable, and weldable. Finally, it must not chemically react (much) with the working fluid or the crystal-growing environment. TZM, an alloy of molybdenum, was selected for both heat pipes.

Both types of heat pipes have been successfully tested and fabricated, and are constantly being improved. Developmental issues have included. treating the inside surface to promote proper fluid flow, minimizing the stresses caused by forming, machining, and welding (lest these stresses cause cracks); and determining the appropriate inventory of working fluid.

The flashlight-shaped heat pipe for epitaxial growth is the more commercializable configuration. Plans to emphasize its development are recommended. This would include testing working fluids that are less dangerous than potassium and fabricating heat pipes that can accept substrate diameters as large as six inches.

This research was performed by Scott Hynek of Foster-Miller, Inc.; (617) 890-3200. The contract was administered by Dr. Brian Ahern, Rome Air Development Center, ESM at Hanscom AFB; (617) 377-3776. ■

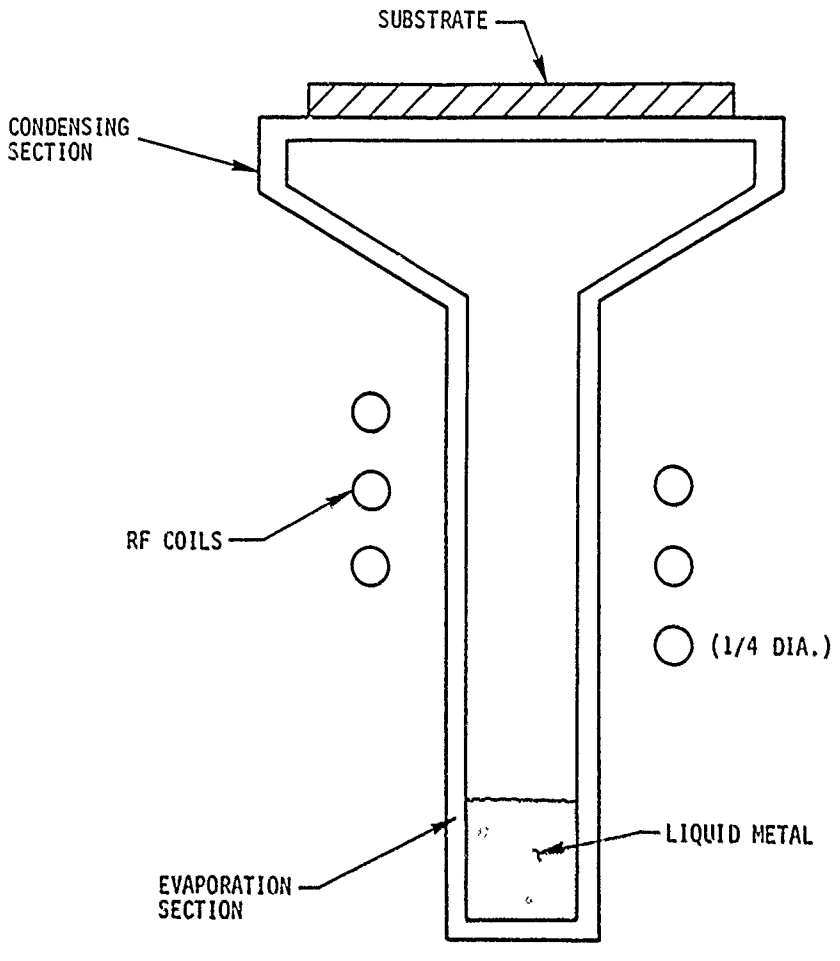


Figure 2
Flashlight-Shaped Heat Pipe

Developing a Radiation Tolerant Photodetector

A novel photodetector has been developed to measure faint optical signals in the presence of ionizing radiation. It is composed of a special solid-state photodetector in a photomultiplier tube, so that the optically generated photocurrents are amplified much more than the radiation induced photocurrents.

Optical photocurrents (signals) are created when the photon generates a photoelectron at the photocathode. Each photoelectron is accelerated to approximately 10 kV before it impinges on the solid-state detector. While an optical photon creates one carrier pair in a solid-state detector, a 10 kV electron creates approximately 3,000 carrier pairs.

The main source of radiation induced photocurrents, however, is direct electron excitation by ionization in a solid-state detector. If the optical efficiency of the photocathode (i.e. electrons per photon) is 7 percent, the gain of the tube (carriers per incident photon) is about 210. Thus, in a properly designed tube the optically generated photocurrent (signal) is enhanced much more than the ionization generated photocurrent (noise). Additionally, the signal-to-noise ratio can be optimized if the solid-state detector is only one (10 KeV) electron range thick. That would make the optical photocurrents (signal) as big as possible, and the ionizing photocurrents as minimal as possible. Finally, if a second identical photodetector in the tube is subjected to the same ionizing radiation, but shielded from the optical photoelectrons, the ionization induced noise in the blind detector can be subtracted from the signal and noise in the sighted detector. An optimized and miniaturized detector has been developed for laser gyro applications and tested to demonstrate the validity of the preceding arguments.

Concept feasibility was demonstrated with an experiment as indicated in figure 1. In this test a photo tube with solid-state detector and an identical solid-state diode on a header were subjected to ionizing radiation from a Cobalt 60 source (about 1 MeV photons). A picoamp meter was used to measure both dark and radiation induced photocurrents of biased and unbiased diodes. The result of this investigation was that the photo tube demonstrated optical gain of approximately 300 while the ionization inducted photocurrent of detectors in a tube was only a factor of 2 greater than those in bare detectors. This means the signal-to-noise was enhanced by about a factor of 150.

Figure 2 represents a special tube developed for laser gyro applications. This is a proximity focused tube with the semiconductor photodiodes located behind an aperture plate. Two kinds of tube body (glass and ceramic) and two kinds of detector were employed. One detector was a double heterostructure, AlGaAs/GaAs diodes, fabricated by Honeywell Opto-Electronics for Sandia National Labs; the other was dielectrically isolated oxygen implanted silicon constructed for this program by Advanced Detector Corporation on wafers obtained from Spire Corporation. The detector thickness was matched as closely as possible to the photo-electron range.

These tubes were only about 1.2 cm in diameter and 1.8 cm long. They were specifically designed for a laser gyro operating at 0.63 micron with an output power of less than 1 microwatt. However, the concepts demonstrated in this program, i.e., signal multiplication, thin solid-state detectors and noise subtraction, could be adapted to any visible electro-optics system which must function in ionizing radiation (i.e. fiber optics, laser communication, and laser radar).

This research was performed by Dr. Burr C. Passenheim and Dr. Larry Acton of Jaycor; (619) 453-6580. The contract was administered by Lt. Eric Bailey and Capt. George LaMar, Ballistic Systems Division/MYET at Norton AFB; (714) 382-2592. ■

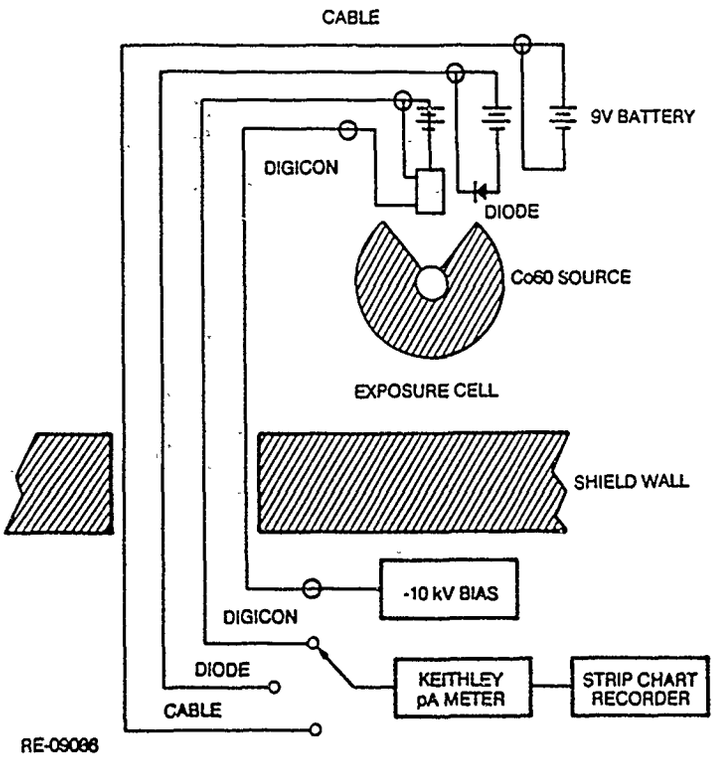


Figure 1
Schematic of the Co-60 Test

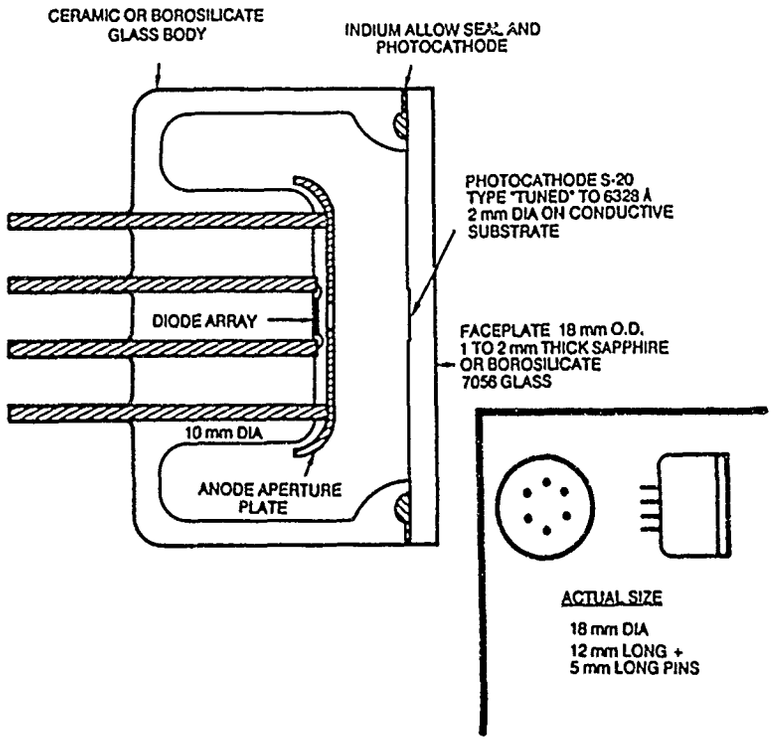


Figure 2
Proximity-Focused Mini-Digicon

Phased Array Imaging in Partially Coherent Light

Long-range target tracking missions are increasingly characterized by extreme acquisition and tracking requirements. They demand systems which return images with high spatial resolution and signal to-noise ratios. Tracking system analysts are investigating phased array optics as a means to achieve increased aperture size, and consequently better images; and greater tracking precision. While theoretical models exist for phased array systems in non-coherent and fully coherent light, the actual target return in an active tracking situation would be intermediate, partially coherent light, for which no accurate model exists.

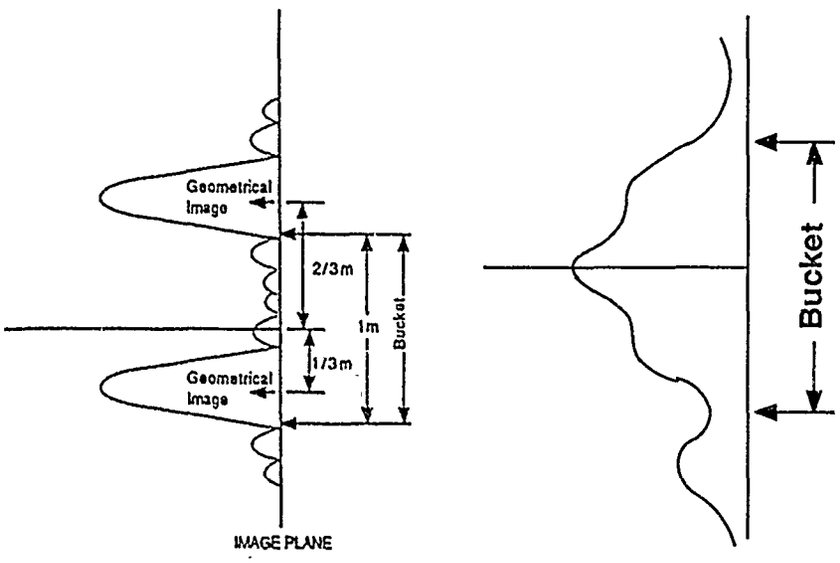
The problem of phased array imaging in partially coherent light is further complicated. Because partial coherence does not produce noise in the classical sense, it superimposes unwanted and highly unpredictable spatial modulation. Therefore, the objective of Phase I work was to develop a theoretical model for partially coherent light. It had to be useful for the design of a pupil plane transmission screen, so that when light from a given source is transmitted through the screen, the power collected in a given object circle is at its optimum.

The approach to solving this problem led to the development of a formalism for maximizing the concentration of energy in a specified image or object circle. By optimizing the absolute encircled energy, an improvement in pupil function was achieved. This became and still is the standard measure of beam quality for laser devices and beam control systems.

The effectiveness of the optimization procedure in concentrating energy within an object circle is most easily explained by the following example. Partially coherent light from a clear lens was propagated onto an object circle. Then a sample was made of the energy collected. Using this measure as a baseline, the optimum pupil function was applied, and a second sample taken. The result was a 20 percent increase in the power collected at the object circle. This information can be used in future target signature characterization and speckle noise reduction studies to produce new algorithms for minimizing the effect of partial coherence. Figure 1 illustrates phased array imaging in partially coherent light. In diagram A, the image plane, intensity distribution of a two-point source, far field target is shown relative to a light collecting "bucket". No pupil optimization has been performed. Diagram B illustrates that when pupil optimization techniques are used, the fraction of energy falling within the collection bucket substantially increases.

While the problem examined was specific to long-range active tracking applications, the technique employed can be extended to many applications. This would include laser communications technologies, laser-based remote sensing studies, commercial camera design, and medical imaging and automatic inspection systems.

This research was performed by Dr. Ahmed Erteza of Applied Technology Associates, Inc.; (505) 247-8371. The contract was administered by Capt. Paul Idell, Weapons Laboratory at Kirtland AFB; (505) 846-4405. ■



(A) No Optimization (B) Optimization Applied

Figure 1
Phased Array Imaging in Partially Coherent Light

A Superconductor-Insulator-Superconductor (SIS) Mixer Block for Application at 100 GHz

Superconductor-Insulator-Superconductor (SIS) mixers are thin film integrated circuits, which operate at temperatures near absolute zero. Like other mixers, they serve to convert high frequency signals to lower frequency receiver systems, however, they do so with much greater efficiency than other mixers based on semiconductors. SIS mixers can be used to build receivers nearly as sensitive as quantum physics allows, which is one reason SIS devices are used in radio astronomy.

In general, however, SIS mixers are laboratory bound and not widely used, due to at least two factors. First, the fabrication of suitable SIS circuits requires expertise and equipment available at only a few locations in the world. Therefore, SIS mixers are very scarce and expensive. Secondly, the requirement that the devices be cooled to near absolute zero during operation necessitates cooling apparatus, which is generally large, heavy, and fragile.

The goal of the program was to produce a manufacturable SIS mixer subassembly including the cooling apparatus for general purposes, and later, for more specialized applications. The entire mixer assembly was to be light, portable, and highly efficient for long unattended operation. In the course of developing the SIS, a superconducting integrated circuit fabrication facility was constructed.

SIS mixers operate through a mechanism called "tunneling", in which electrons are conducted through extremely thin insulating films by virtue of the uncertainty principle. At very low temperatures, the metal electrodes become superconducting, which tends to prevent current flow except above a certain voltage (energy gap voltage). In a high quality SIS device, the current increases extremely rapidly as the voltage exceeds the energy gap voltage; therefore, the device is highly nonlinear. This nonlinearity is exploited in mixers to change one frequency to another, and the more nonlinear the mixer, the more energy is converted.

Because the SIS device can show the highest nonlinearity known, not surprisingly, they are the best mixers. What is surprising is that when the frequencies are above 30 GHz, SIS devices are so nonlinear that quantum mechanics must be used to predict performance. The quantum mechanical calculations and observations show that an SIS mixer actually provides conversion gain, or amplification, something that is impossible according to the classical (non quantum) theory.

In order to produce an SIS mixer assembly, a fabrication process had to be developed and refined. The developed process is capable of producing the highest quality tunnel junctions, as well as inductors, capacitors, transmission lines, and other circuit elements. These elements were fabricated on small quartz substrates, which were cooled to 4.2 Kelvin by liquid helium. The dewar, which contains the helium, and the mechanical structure, which supports the chip and allows electrical contacts to be made, were designed to have very low thermal loss. This maximized the operating time between recharging with helium. The entire assembly is 18 inches tall and 9 inches in diameter, therefore making it easy to transport. The unit is now available for field testing and evaluation for possible applications in secure communications, surveillance, and RADAR. The mechanical ruggedness and small size should facilitate airborne, as well as terrestrial deployment.

This research was performed by S.R. Whiteley of Hypres, Inc., (914) 592-1190. The contract was administered by Harold Weinstock, Air Force Office of Scientific Research, N5 at Bolling AFB; (202) 767-4933. ■

Hardened Remote Digital Data Acquisition System

The Air Force and other high explosive technicians are clearly in need of improved measurement systems to diagnose high explosive detonation effects. With a better measurement system, the accuracy and precision of data would reduce the number of tests as well as required equipment. This, in turn, would reduce test costs. Development of such a system was the primary goal of this project.

High explosive induced ground shock and airblast are used to simulate the effects of a nuclear detonation on geological media and structures. Currently, state of the-art measurement systems that record detonation data employ long hard wire connections between transducers and data acquisition systems. Cable length therefore becomes a limitation in acquiring high frequency data. The development of an eight-channel Hardened Remote Digital Data Acquisition System would reduce the number of instrumentation recording vans required at a test site. Such a system, placed just outside the crater region of a high explosive test, would enhance data bandwidth and reduce test cost by eliminating seven out of eight long (4,000 6,000 ft) data cables and two of three instrumentation trailers.

The design process employed to develop the data acquisition system centered around electronic circuit designs. These designs had to meet or exceed the capabilities of current analog data acquisition systems and use state of the-art components mounted on very high density printed circuit boards. Custom integrated circuit components were far too costly to be employed. The data acquisition system was to be no more expensive than existing systems, which cost approximately $2,500 per channel. The majority of the design process encompassed identifying suitable components and integrating them into circuits

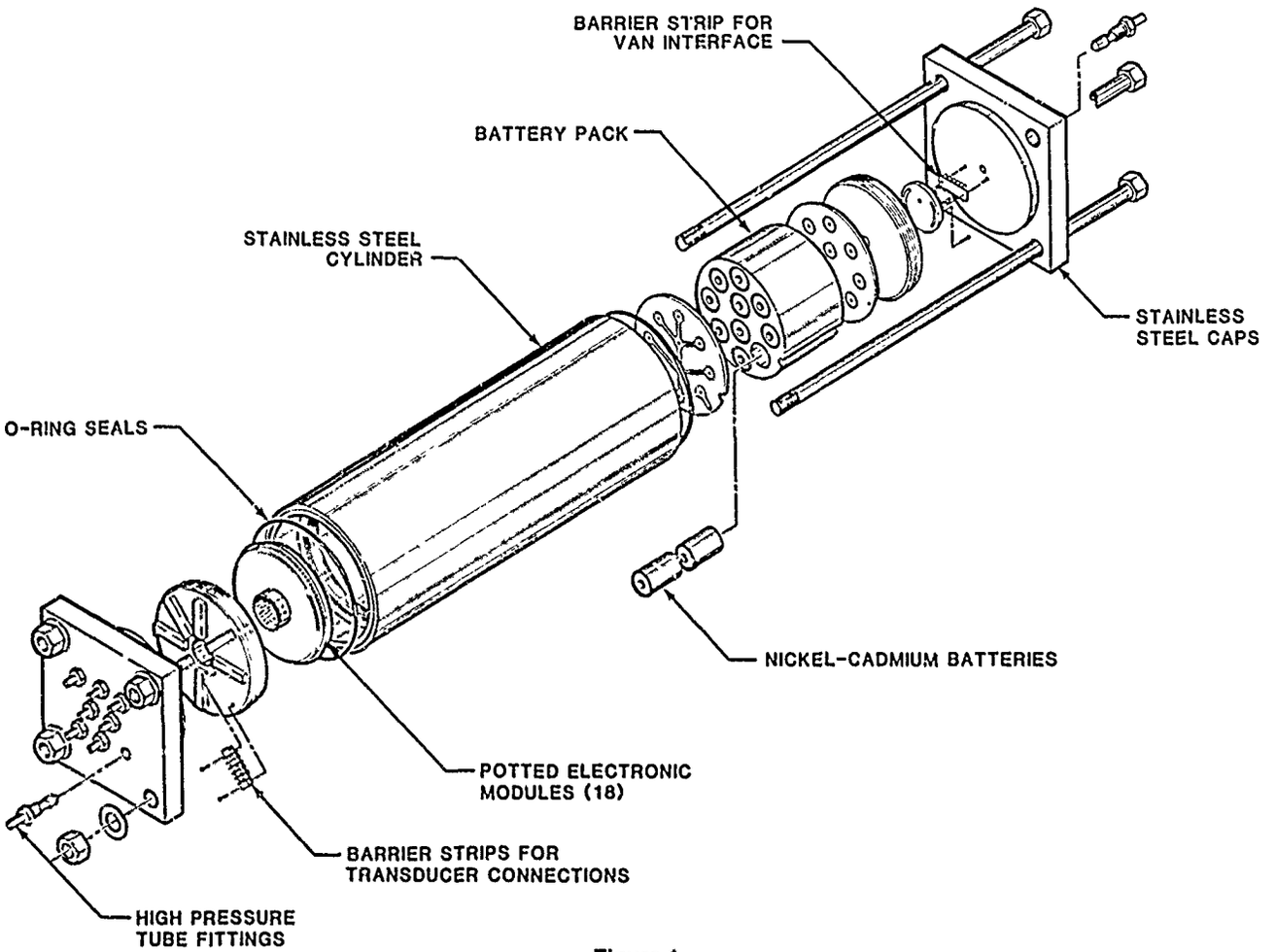


Figure 1
The Hardened Remote Digital Data Acquisition System

to provide the desired data acquisition functions.

Shock hardness of the system is provided by immobilizing shock hardened components within a pressure vessel that withstands 14,500 psi. Plastic pack integrated circuits were used whenever possible. A few components were not available in plastic packages, so a technique was developed to remove the lids from the integrated circuit packages and fill them with epoxy to ensure shock hardness. All of the components used in the digital data acquisition system have been impact tested to 20,000 g's with no failures.

Overall system design included developing a package as small and light as possible, while maintaining the required shock hardness. Also, the system had to be two-man portable, so it could be easily placed in a high explosive test bed. A tubular stainless steel housing was employed to provide maximum pressure stand-off with minimum weight. The printed circuit boards were circular and as compact as possible. Each circuit board was potted with a micro-balloon filled with epoxy to immobilize all of the components on the boards.

Software was developed to control the embedded processor-based digital system and provide user control of all programmable system parameters with a simple terminal. The design included an on-board microprocessor to allow for maximum flexibility of system use. It was limited only by the capability of the components.

The eight-channel Hardened Remote Digital Data Acquisition System configuration is illustrated in figure 1. The complete system has not yet been built; it lacks only final design of the battery pack and the printed circuit board for the power regulation module. The electronic system is operational and has been demonstrated to meet or exceed all specifications.

The specifications for each channel include: 1) microprocessor control with programmable transducer excitation voltage from 0 to 12 VDC; 2) a two-stage programmable amplifier with gains from 1 to 800 with a high impedance differential input amplifier, 3) a programmable four-pole linear-phase (Bessel function) anti-aliasing filter with cut-off frequencies of 5, 10, 25, 50 and 100 kHz; 4) programmable or automatic DC offset control; 5) programmable variable sampling rate from a 2 μs to 125 ms interval per data point with 12-bit resolution; and 6) memory to store 122,880 data points. Each programmable parameter can be changed during data acquisition at every 4,096 data point memory partition. The channel programming and programmable parameter values can be downloaded from a host computer or the parameters can be entered from a terminal.

The system has a RS-422 serial interface and rechargeable nickel-cadmium battery pack. The batteries provide a two-minute system operating capacity, if external power is lost during the test event. The data memory is then retained for one week to allow excavation and recovery of the system. The system can be triggered to start data acquisition with an external signal, by an internal clock/calendar setting, or by data from the test event.

The Hardened Remote Digital Data Acquisition System will provide the Air Force and other high explosive test participants with the capability to acquire high frequency data never before recorded. Use of this system also reduces the cost of conducting high explosive tests by diminishing the number of recording/instrumentation trailers and long data cables. Other advantages of the system are decreases in data reduction time and quick look data reduction. This is accomplished in the field immediately after the test event. Overall, the system provides increased capability, while reducing the cost of high explosive testing.

This research was performed by David J. Fogelson of Ktech Corporation, (505) 268 3379. The contract was administered by Lt. C. Jorgenson, Weapons Lab/NTEO at Kirtland AFB; (505) 846-7210. ■

Implementation of an Ionospheric—Image File Management, Processing and Display System

The Ionospheric Image Processing System (IIPS) is a workstation designed to support the analysis of image data at the Air Force Geophysics Laboratory (AFGL). While the system provides many generic image processing functions, its primary focus is on All-Sky Imaging Photometer (ASIP) imagery from ground-based and airborne cameras. Recorded by automated systems in a variety of dedicated observational campaigns, a large number, perhaps millions, of these images currently exist in the film and videotape archives at AFGL and other institutions. The collection of these data is expected to continue in the future. IIPS is a microcomputer-based workstation with facilities for processing, displaying, storing, and retrieving the ASIP image data. It is intended to be used in the analysis and interpretation of these data as well as provide image library management tools for their archival.

The ground-based ASIP cameras operate automatically during the northern polar night, roughly November through February. Currently, there are two stations in Greenland (Qanaq and Sondrestromfjord) and one in Spitsbergen (Longyearbyen). Images are recorded on 35-mm film reels at the nominal rate of one per minute. In the standard configuration, alternate images are filtered by 4278 and 6300 Å filters, and light is gathered by a 155-degree field-of-view lens. The camera axis is vertical. The aircraft system is part of the AFGL Airborne Ionospheric Observatory (AIO). It can operate either on the ground while the airplane is parked or in flight. Data collection with this system is more intensive than with the automated systems, but operations typically last only a few days in support of specific experiments. Images are recorded on videotape nominally at six frames per minute, and a subset of those images are also captured digitally. Image data have been gathered with the AIO system in both hemispheres in all seasons. In a typical year about 200,000 and 50,000 useful images are obtained by the ground-based and aircraft systems, respectively.

The ASIP observational record provides a nearly continuous record of auroral and airglow activity as illustrated in figure 1. It also contributes important information on both small and large-scale phenomenology. Interpretation of these data is complicated, however, by the geometrical distortions inherent with all imaging systems, particularly with upward-looking, wide-angle observations. Ultimately, the ionospheric researcher would like to see a polar-cap scale view of the ionosphere including all relevant concurrent images of a particular phenomenon. In raw form, however, the component images are in distinct coordinate systems. The polar systems are attached to each camera, and within each view the "fish-eye" lens distorts. The latter distortion produces an approximate five-fold radial compression near the limb relative to the center. A variety of other photometric and geometric distortions also are present as a result of the camera's projection of the emissions from ionospheric

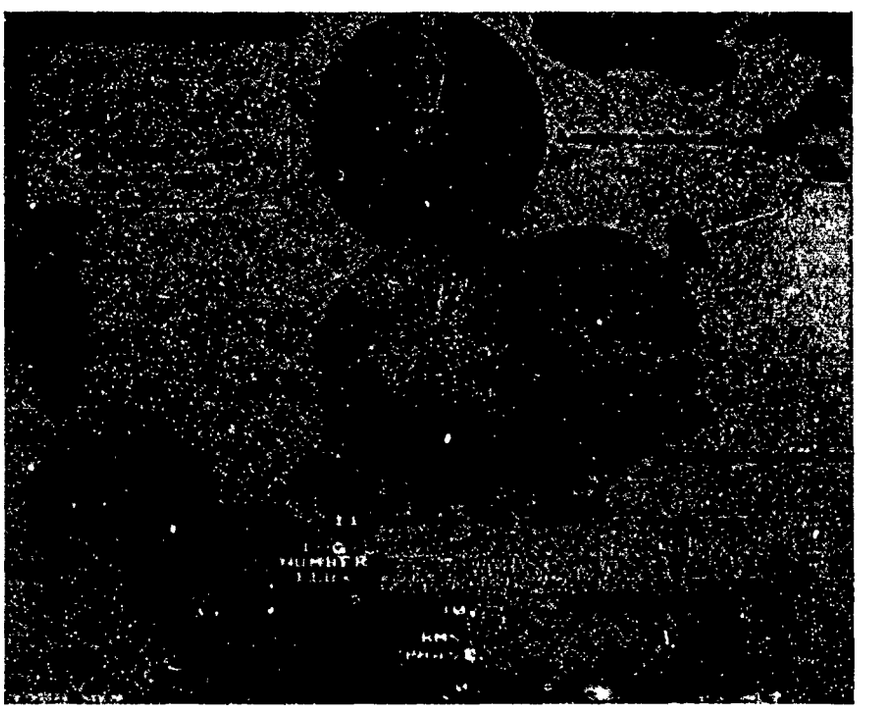


Figure 1
ASIP Images

phenomena of interest onto the film plane (or video signal receptor).

The Phase I project, completed in 1985, established the feasibility of a microcomputer-based system that would support the management, digital processing, and interpretation of ASIP images and correlative data from a variety of other sources (e.g., incoherent-scatter radar, AIRS UV images, and orbital in situ and beacon scintillation measurements). The IIPS workstation was the culmination of the follow-on Phase II project.

The IIPS workstation consists of the following major hardware components: host computer, image processing board, RGB monitor, monochrome TV monitor, film recorder, printer, video camera, 35-mm film transport and projector, and optical videodisc recorder. With the exception of the film recorder, all components can be controlled by the host computer. (Optional manual operation is also available in most cases.) Images can be copied from film to the videodisc medium, for example, under computer control. This automated operation makes it practical to transfer the film-based images to videodiscs. Once this is done, the operator gains fast, interactive, visual access to any of up to 16,000 images on a single disc.

The host computer is a standard IBM PC/AT, capable of running all DOS-compatible software. Special programs have been developed to support specific IIPS functions. These include IMAGES (interactive control of the film transport and videodisc subsystems), ASIPGEO and GENIM (geometric restoration of image data), GEOPLOT (projection and plotting of geographical data), REGGIE (registration of ASIP image data), and OMNI (general-purpose image processing and graphics). The latter program is a menu-based interactive "toolbox" and includes a context-sensitive help system. Its extensive functionality should be accessible to users regardless of their level of experience. EDPAR is a utility program providing a menu-based parameter file editing capability for preparing parameter files needed for runs of ASIPGEO, GENIM, and GEOPLOT.

IIPS was designed to support the analysis of ASIP image data as well as a variety of other image and nonimage data relevant to ionospheric science. Source data can be in the form of film or video images or digital data in arbitrary formats. Raw and processed image data can be viewed interactively on the RGB and TV monitors, or saved in digital or analog (videodisc or film hardcopy) formats.

This research was performed by R. David Lucas of Northwest Research Associates, Inc.; (206) 453-8141. The contract was administered by Dr. Edward Weber, Geophysic Lab at Hanscom AFB; (617) 377-3121. ■

Numerical Simulation of High Speed Heterostructure Bipolar Transistors

Aluminum gallium arsenide (AlGaAs)/gallium arsenide (GaAs) heterostructure bipolar transistors (HBT) have great promise for high speed applications. Because both are discrete devices in circuits, they have applications in the Air Force's avionics, missile, and space programs. Fabrication of these structures is currently underway in many laboratories in the U.S. and abroad. At early stages of the development, numerical simulation of the device, based on fundamental concepts, reduced the number of costly trial runs and served as a design aid. The objective of this project was to evaluate the suitability and limitations, if any, of the HBT for high speed applications, and to suggest design modifications which would meet specifications required by the applications.

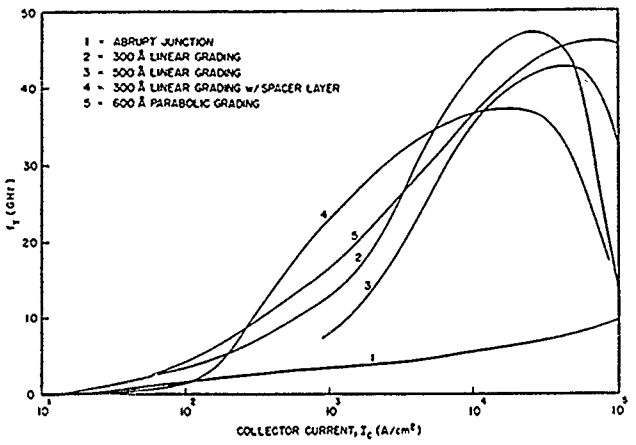
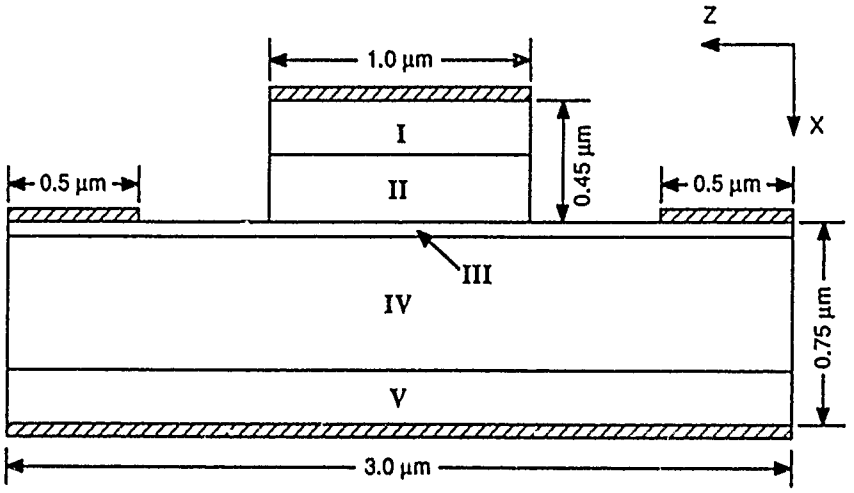


Figure 2
Effect of Aluminum Grading on Frequency

The device structure under consideration is shown in figure 1. It is very similar to that fabricated by the Rockwell group. Some of the key design parameters which affect the performance of the device are the emitter doping, base width, base doping, collector thickness, composition of aluminum used, and nature of aluminum variation in the emitter. The variables related to the operation of the device are collector voltage, base voltage or current, and associated circuit parameters.

The number of variables available to the device designer is large. Optimizing the variables to obtain the expected performance for a given application is a difficult task. In this regard, a numerical simulation of the device, based on sound fundamental concepts, can be a cost-effective adjunct to the fabrication of new devices. A large number of simulations were performed using SRA's semiconductor drift and diffusion computer code. This code is capable of solving the drift and diffusion (DDE) and Poisson's equations in multi-dimensions. The equations describe the physics of semiconductor devices, subject to certain approximations.



I	0.20 µm		n^+	AlGaAs	2×10^{18}
II	0.25 µm	EMITTER	n	AlGaAs	5×10^{17}
III	0.05 µm	BASE	p^+	GaAs	1×10^{19}
IV	0.50 µm	COLLECTOR	n	GaAs	5×10^{16}
V	0.20 µm	SUBSTRATE	n^+	GaAs	2×10^{18}

Figure 1
Schematic of the Heterostructure Bipolar Transistor

The parametric study conducted involved a systematic variation of the value of a single variable, while keeping all other parameters constant. The following describes some of the parametric studies.

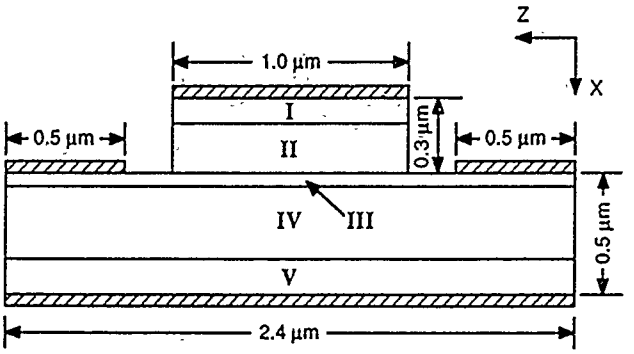
Composition of aluminum must be graded in the emitter, so that the device can turn-on and conduct current at small values of voltage on the base contact. The nature of grading and the grading width are two issues which remain unclear in the HBT community. In this study, various types of grading in the emitter were considered, for instance, linear and parabolic profiles. In addition, several grading widths were studied. The results, in terms of the impact on achievable frequency of operations, are shown in figure 2. It was concluded, based on over-all considerations, that a 300 angstrom linearly varying compositional grading gave the best performance.

In addition to providing the type of information previously described, a numerical simulation can provide understanding and insight into the operational characteristics of the device. For example, a typical current flow pattern inside the device, as simulated in the study, is shown in figure 3. A quick glance reveals that there is no region where the current is crowded. Current crowding, if present, leads to burn out of the device.

From the detailed understanding gained from several such parametric studies, an optimum device configuration was derived to obtain high frequency performance. The proposed structure is shown in figure 4. The results from this study are to be communicated to other Air Force contractors. In addition, a user friendly version of the code used in this project is currently under development. This code is capable of providing design information through careful parametric analysis.

In summary, a design-oriented computer simulation study was conducted to evaluate the heterostructure bipolar transistor for high frequency applications. The study provided an important understanding of the operational principles of the devices and design information for improved performance.

This research was performed by Dr. Harold L. Grubin of Scientific Research Associates, Inc.; (203) 659-0333. The contract was administered by Chern Huang, Wright Research Development Center/Avionics Laboratory at Wright-Patterson AFB; (513) 255-8648. ■



I	0.10 µm		n^+	AlGaAs	2×10^{18}
II	0.20 µm	EMITTER	n	AlGaAs	5×10^{17}
III	0.05 µm	BASE	p^+	GaAs	1×10^{19}
IV	0.30 µm	COLLECTOR	n	GaAs	1×10^{17}
V	0.20 µm	SUBSTRATE	n^+	GaAs	2×10^{18}

Figure 4
Optimized Structure for High Frequency Performance

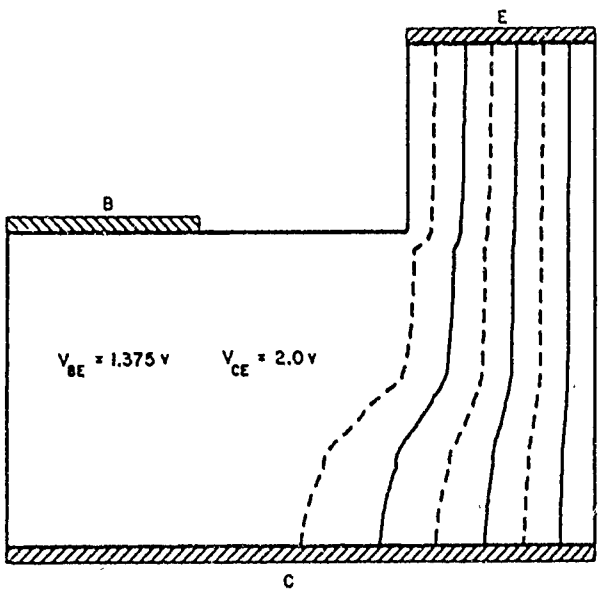


Figure 3
Typical Current Flow Pattern

Fixed Abrasive Slicing Technique (FAST): A Technique for Producing Lower Cost Solar Cells for Spacecraft Applications

Single crystal gallium arsenide (GaAs) and germanium (Ge) are increasingly important electronic materials, which are currently being used for high efficiency solar cells in space. Critical application of these materials serve as the basis for high speed electro-optical devices and digital integrated circuits (ICs). As more and more complex electronics are incorporated into modern spacecraft, improved quality, reliability, and cost will become of greater concern.

Conventional slicing of semiconductor materials is carried out using the internal diameter (ID) technique. This process, although highly developed, uses a high-speed rotating blade which contacts the workpiece at high feed forces. Under these conditions, for a brittle material such as GaAs or Ge, the damage introduced in the sliced surfaces is considerable. Therefore, the wafers are sliced thicker. For most applications, thinner wafers could be used, resulting in improved performance. So, if the slice thickness and material loss surface damage can be reduced, there would be an improvement in the substrate quality. This, in turn, would result in significant cost savings.

Recognizing that ingot technologies were limited by the slicing methods, a new wire technique called the Fixed Abrasive Slicing Technique (FAST) was developed. This achieved high material utilization, high reliability, and the expendable cost. FAST diamonds were plated on the cutting edge of wires which were clamped in a wire-pack. The wires were pulled taut and reciprocated in a straight line as shown in the FAST slicing machine in figure 1.

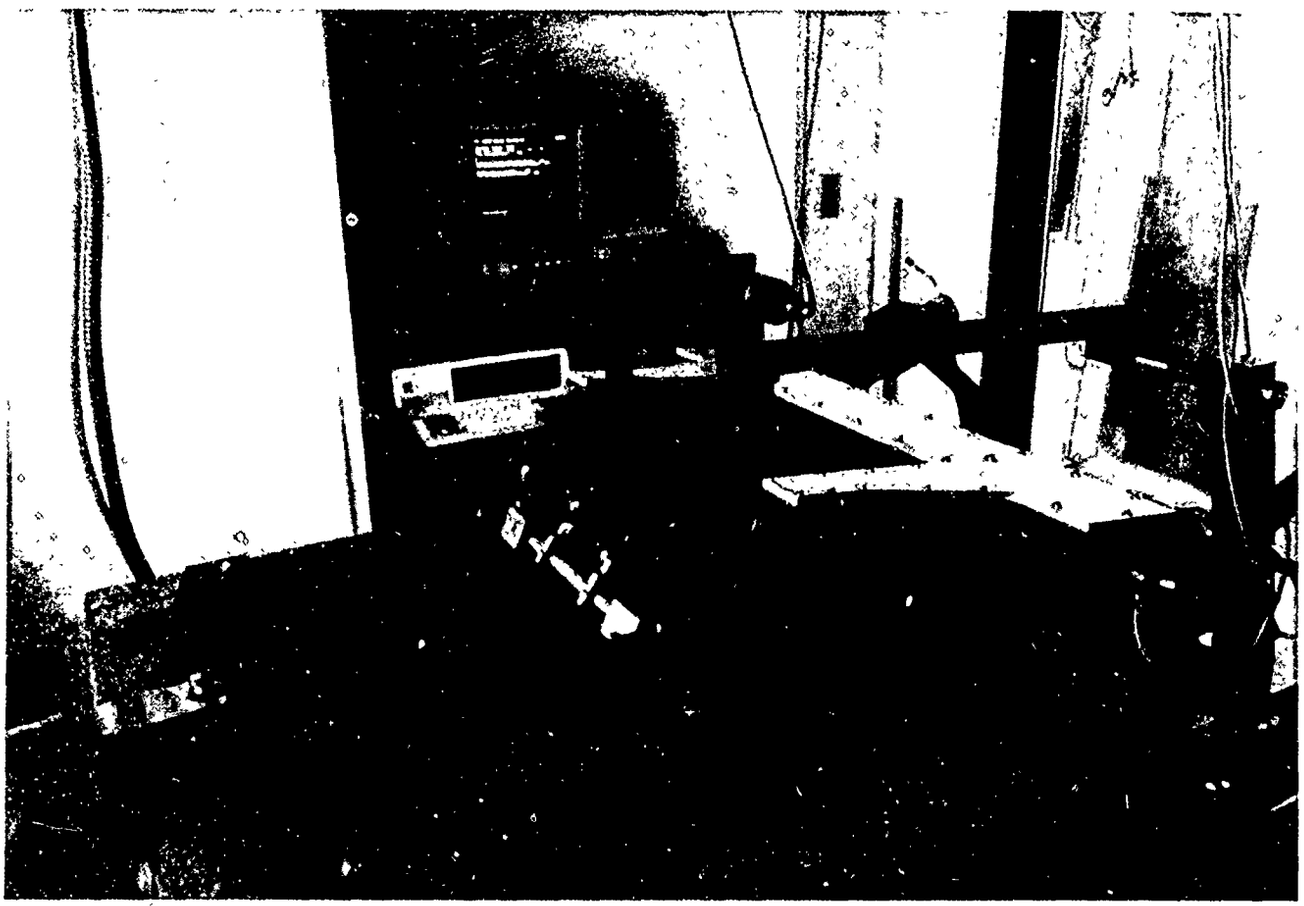


Figure 1
Bladehead Module with Sensitive Feed Mechanism

Much higher utilization can be achieved with wire. Because wire contacted the material only at the point where it was being cut, it allowed for slicing thinner wafers with less kerf width and surface damage.

The primary goal of this program was to develop the FAST machine and its use to cut semiconductor materials into wafers, so that it would meet or exceed the current state-of-the-art. Upon completion of the program, slicing services would be provided to industry as a first step toward commercialization. The approach to accomplishing technical goals was conducted in three areas: 1) process development; 2) blade development; and 3) testing and characterization.

In order to slice GaAs crystals effectively, various modifications were made to the slicer. For example, incorporating a sensitive feed mechanism and increasing the rocking angle for the crystal were just a few of the changes made. Emphasis was placed on wafer throughput and wafer accuracy. In addition, other minor machine modifications were made, such as improvement to the wire blade and the monitoring process of the slicing test results.

Because the crystal was being forced against multiple wires in FAST slicing, it was then necessary to ensure that the cutting was effective and uniform. A good example is diamond plating. Achieving a high concentration of diamonds on the wire with uniform plating thickness was accomplished by the electro formed plating process. A predetermined controlled thickness of diamond was plated only on the cutting edge of the wires. The wire bladepack was initially tested by slicing a silicon block so that a "dressing" of the wires was achieved. Figure 2 is a partially cut silicon block, illustrating the cutting effectiveness of all the wires.

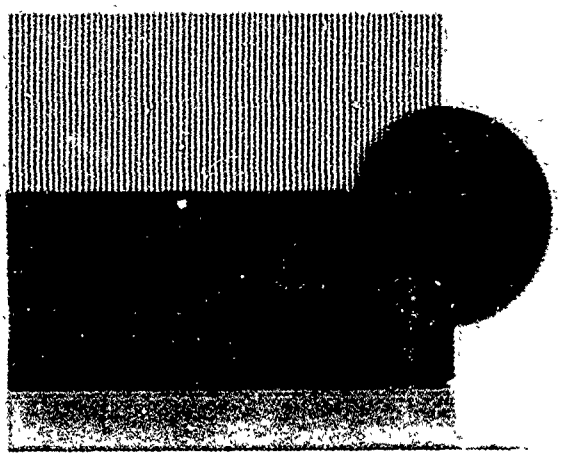


Figure 2
Partially Cut Silicon Block

Since GaAs is softer than silicon, the diamond sizes chosen for slicing GaAs were 15 and 22 μm size. These sizes were found to be effective for GaAs slicing as compared to the 30 and 45 μm sizes used for silicon slicing. Smaller diamond sizes were available with better micronization, i.e. variation in the size of diamonds was considerably less. This allowed for more uniformity in plating, and consequently, smaller kerf and more accuracy in slicing. No diamond degradation was observed in slicing of GaAs crystals. The ability to use smaller diamonds was important to obtain high material utilization of GaAs crystals and to produce wafers with improved accuracy.

Several single crystal bars were polished on one side so that they could be partially sliced. Then they were removed from the slicer for examination of the slots and evaluation of exit chipping caused by the diamond abrasive. The crystal samples were sliced with FAST and similar samples were sliced using the ID technique. A comparison of the grooves for these two techniques is shown in figure 3.

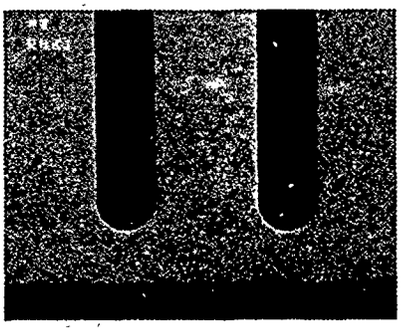
While no attempt was made to quantify the damage due to slicing, the direct comparison of the grooves in figure 3 shows that chipping during slicing in FAST was much less than that in the ID technique. The sliced surfaces of wafers, shown in figure 4, exhibit improved smoothness with the FAST wafers. The as-sawn slices were cleaned in a 10:1, $H_2SO_4.H_2O_2$ etch to remove the submicron particles of sawing debris. It can be clearly seen that the surface damage on the FAST sliced wafers is considerably less than the ID sliced wafers.

Bulk rectangular cross section GaAs crystals grown by the Horizontal Bridgman technique with oriented <100> surfaces were sliced with FAST to yield <100> GaAs wafers for space solar cells. The 2 cm x 4 cm wafers were sliced using 0.125 mm diameter core wire plated with 22 μm diamonds. The kerf loss achieved was 0.165 mm. The average wafer thickness was 0.414 mm with maximum wafer-to-wafer thickness variation of $\pm$ 15 μm.

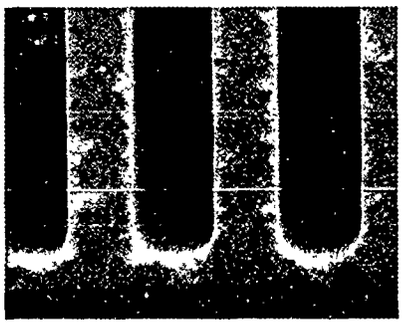
A similar GaAs crystal was sliced with FAST using a bladepack with a wire spacing of 25 wires per linear cm. A 100 percent slicing yield was achieved; producing 128 D-shaped Horizontal Bridgman grown GaAs wafers. The average wafer thickness was 0.220 mm and kerf was 0.180 mm. The FAST slicer throughput was approximately one wafer per minute, which was at least twice the present state-of-the-art. Further slicing of GaAs crystals for solar cell applications is currently underway. These wafers will be quantified for dimensional accuracy, surface damage, slicing time, and material utilization. GaAs crystals will be sliced by ID and FAST and processed together for fabrication of solar cells and testing.

FAST has been adapted for effective slicing of GaAs crystals. Modifications to the slicer have been made in order to improve wafer accuracy. FAST sliced wafers have been compared with ID sliced samples and it was shown that the surface quality of FAST sliced wafers was superior. It was also shown that 0.220 mm thick wafers could be sliced with FAST with no wafer breakage. The material utilization of 25 wafers per linear cm (64 per inch) of crystal was demonstrated with FAST; therefore, twice as many wafers can be produced as compared to ID slicing of the same size GaAs crystal. The combination of high material utilization, low surface damage, high throughput, and high slicing yields makes FAST an ideal choice for slicing GaAs crystals and other exotic semiconductor materials.

This research was performed by Maynard B. Smith of Crystal Systems, Inc.; (508) 745-0088. The contract was administered by Terry Trumble, Wright Research Development Center/POOC at Wright-Patterson AFB; (503) 255-6235. ■

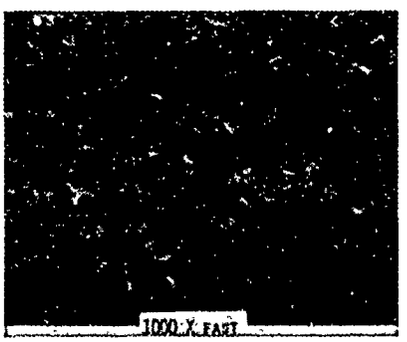


(a) FAST



(b) ID

Figure 3
Comparison of Microchipping in FAST and ID Slicing



(a) FAST

(b) ID

Figure 4
Surface of FAST and ID Sliced Wafers

Chemical Vapor Infiltration Processing for Structural Ceramic Composites

A considerable amount of effort is expended in this country and abroad to develop lightweight ceramic materials that can operate at elevated temperatures in a turbine engine environment. Powder compacted silicon carbide and silicon nitride fabricated by hot pressing, reaction bonding, and sintering are promising candidates. However, they are limited in their potential by an inherent brittleness and lack of fracture toughness. It appears toughness can be achieved more easily through a two phase or composite system where fiber reinforcement acts as a crack arrestor and provides an increase in the required work of fracture.

Newly developed silicon carbide fiber-reinforced glass matrix composites, for example, have demonstrated good fracture toughness; however, these materials are limited in tempera ture capability by the matrix properties. The development of a tough ceramic composite usable in the 1100°-1500°C range would provide a material with significant potential for advanced gas turbine engine components. A number of programs are currently underway involving fiber reinforced refractory matrix composites. This includes both polymer and powder processes.

The purpose of this program was to define the potential for this approach and specify the direction for future development. The scope was limited to evaluating composi tions consisting of a silicon carbide matrix with the primary reinforcing yarn being NICALON, the Japanese silicon carbide fiber. The research explored the structure of the reinforcement, the fiber matrix interface, the vapor deposition process, and the resulting composite microstruc ture. The investigation included testing for strength, toughness, oxidation resistance, and thermal shock.

Testing the feasibility of fabricating fiber-reinforced ceramic matrix composites via chemical vapor infiltration (CVI) became part of the mission. The infiltration of carbon/carbon and ceramic textile preforms with a refractory matrix through a gas phase reaction has been the subject of research for a number of years, especially in Europe by the Societe Europeenne de Propulsion (SEP). SEP has produced material samples that were tested and found to exhibit considerable promise as a tough, structural ceramic.

Ceramic matrix composites exhibiting non catastrophic failure at temperatures exceeding 1200°C in air have been fabricated by chemical vapor infiltration. In-plane tensile strengths above 150 MPa(23 ksi) were measured at 1193°C with strain-to-failure exceeding 0.35 percent. Fracture toughness measurements indicated a maximum stress intensity factor of 21.9 $MPa \cdot m^{1/2}$ (19.9 $ksi \cdot in^{1/2}$) at room tempera ture with a 13 percent decrease

Figure 1
Two-dimensional Flap Engine Component

after a 100-hour soak in air at 1200°C. Thermal shock specimens heated in air and then quenched in water showed no loss in retained flexure strength for quench temperatures up to 1000°C. Instrumented impact tests showed composite behavior with the maximum absorbed energy being 3.0 J/cm^2 (14.4 ft-lb/in^2).

The strength and toughness of the composite were shown to be sensitive to the chemistry of the fiber surface. Fiber coatings were necessary to provide the proper interfacial bonding between fiber and matrix. Thin coatings on the NICALON fiber preforms were produced by varying the CVI deposition parameters. The coated fibers were protected by the matrix during static exposure in air. Adverse oxidation effects or thermal degradation were not evident below 1250°C.

A three dimensional braided fiber architecture was studied as a representative preform for evaluating composite materials for engine components. In addition to providing reinforcement in three directions, three-dimensional braiding has the potential for near net shape, automated fabrication of complex shapes such as turbine rotors and blades. With relatively high fiber loadings and a pore distribution that provided integral gas paths, the three-dimensional architecture was found to be well suited to CVI processing.

The chemical vapor infiltration of silicon carbide into fibrous preforms was studied analytically and experimentally. To prevent premature closing of pores by surface deposition and non-uniform densities, it was necessary to select operating conditions that resulted in low reaction rates and high diffusion coefficients. Low temperature, low pressure operation in an isothermal system required processing innovations to reduce the normally long run times. Processing variations, including non-isothermal temperature and pressure gradient methods, were also evaluated. Typically, composite specimens with thickness greater than 5 mm (0.2 inches) were processed to a bulk density of 2.4g/cc (80% of theoretical) with processing times of 60 hours or less.

Material characterization included: 1) flexure (4-point bend) and tensile testing in air at room and elevated temperatures; 2) measurements of retained flexure strength after 10-100 hours exposure in air at temperatures up to 1500°C; 3) thermal shock tests measuring retained strength after a water quench; 4) instrumented impact tests (3-point blend) of specimens before and after heat treatment; and 5) fracture toughness by single-edge notched beam method. In addition, the coefficient of thermal expansion was measured from room temperature to 1000°C. Data on specific heat, thermal diffusivity, and thermal conductivity were obtained.

The results of the mechanical and thermal test indicated that the CVI process was a promising approach for producing near net shape structural ceramic components, which operate in an oxidizing environment at elevated temperatures and retain both strength and toughness. The direct outcome was the involvement of major turbine engine companies in the evaluation of the CVI processed NICALON/silicon carbide composite in specimen and prototype component forms. One of the most successful programs was the preform development and matrix infiltration of a full scale, two-dimensional nozzle flap. This prototype ceramic composite component is shown in figure 1. It was tested in an engine environment and performed above expectations. The design required near net shape processing of a complex shape that included varying thickness, hat-shaped stiffeners, and a structural hinge line. Only a minimum of surface finishing was required after matrix densification.

The CVI processed ceramic matrix composites are expected to play a major role in the Air Force Integrated High-Performance Turbine Engine Technology (IHPTET) program and other advanced man-rated and limited-life turbine engine developments. Current plans include coupon and prototype testing and rig tests in an Air Force managed program. A three-year CVI processing science program for ceramic matrix composites will be awarded this year to a national laboratory.

Other applications for these ceramic materials currently being evaluated include aero-orbiting vehicles, space structures, and industrial/commercial uses. The Department of Energy recently awarded two contracts to study advanced concepts for high pressure industrial heat exchangers that utilize ceramic matrix composites. At least one of these programs will utilize the CVI processed NICALON/silicon carbide data base in the design studies. A consortium of gas utilities and the Gas Research Institute support a program that could lead to the commercialization of advanced radiant burner tubes for industrial gas furnaces. The selected material configuration for these tubes is fiber reinforced silicon carbide produced by CVI processing.

This research was performed by Curtis V. Burkland of Amercom, (818) 882-4821. The contract was administered by Dr. Alan P. Katz, Wright Research Development Center/MUM at Wright-Patterson AFB; (513) 255-9820. ■

High Temperature Resistant, High Strength Plastic Composites

For many years fiber-filled plastic composites, such as fiberglass, have been successfully replacing metals in low performance applications. To meet the demands of high stress applications such as aircraft, however, the strength and thermal stability of composites must be increased. Progress in these areas has been made by constantly gaining small improvements in the plastic, or polymer matrix materials, as well as in the size, shape, and composition of the fibers.

Many fundamental problems remain, however, with this more-or-less standard approach to enhancing composite properties. Paramount are the problems of uniform distribution of fiber in the polymer and adhesion between these two dissimilar materials. Air Force researchers introduced a new class of materials termed molecular composites, which eliminated these problems. The fibers were replaced by long, rigid polymer molecules, similar in structure to the polymer matrix. The key to this work was the ability to make long rodlike molecules and then distribute them uniformly in a thermally stable polymer matrix. The Air Force efforts resulted in several successful rigid and polymer technologies. Molecular composites of this type show outstanding mechanical properties under both ambient and elevated temperature conditions. They have the drawback, however, of being extremely difficult to process because of the insoluble nature of the rigid rod polymer component.

The purpose of this program was to develop more easily processed molecular composites which retain good high temperature performance. As the basis for the work, a family of polymers was selected. These polymers have to possess the ability to undergo a thermal rearrangement to a rigid rod form when heated in the 200°-300°C range. The precursor form has the advantage of being highly soluble in organic solvents, which greatly simplifies composite processing. Unfortunately, the precursor also has the disadvantage that water is generated when it converts to the final product. To overcome this problem, the chemical structure of the precursor has to be altered significantly. The approach shown to be feasible in Phase I was to attach long side chain molecules at recurring sites along the precursor. This process has to be versatile for many side chain chemistries and no sites can be left unmodified.

All of the commonly known synthesis methods were tested for producing the desired precursors, but these efforts were largely unsuccessful. Consequently, a new synthetic technique was developed (patent pending) which was facile and could be conducted at room temperature with a good yield of the precursor polymer. The reaction scheme was ideal for scale-up in a production setting.

The new technique was used to produce a variety of precursor forms. The model materials were

Curing Cycle*	Modulus (GPa)	Elongation (%)	Ultimate Strength (GPa)
60C/1 hr.	1.53	8.3	0.07
60C/1 hr. 185C/1.5 hr. 200C/1.5 hr.	2.19	5.6	0.05
60C/1 hr. 185C/1.5 hr. 250C/1.5 hr.	6.23	7.3	0.29
60C/1 hr. 185C/1.5 hr. 300C/1.5 hr	6.69	5.6	0.30
60C/1 hr. 185C/1.5 hr. 350C/1.5 hr.	21.21	4.7	0.46
60C/1 hr. 185C/1.5 hr. 400C/1.5 hr.	81.04	2.7	0.79

*All cures of 200°C or higher were conducted under nitrogen.

Table 1
Curing Cycles and Mechanical Properties for Polyamic Diethylamide Films

especially useful at this point in the program for studying how flexible coil polymers rearrange into rigid rod species. Moreover, they could be blended with common matrix materials, such as epoxies and bismaleimides, and then heat treated to give molecular composites. After preparing some of these mixtures, it was found that the final products were clear (which is a sign of good compatibility in the composite) and very tough. Studying how to combine the rigid and precursors with thermoplastic matrix materials to produce molecular composites with exceptionally high temperature stability has begun.

In conjunction with the chemistry aspect of the project, additional research on ways to measure the integrity and mechanical strength of these new composites was being investigated. Two approaches were taken. The first was to mold small rectangular coupons and subject them to standard ASTM testing. This traditional approach can be very time consuming and required extensive process research. To expedite mechanical property determination, thin film testing methods were used. The composite materials were cast from solution to form thin films which were easily cured and tested. Results of these studies appear in table 1. The results were consistent with the conversion of a flexible coil polymer to a rigid rod form as the cure temperature increased.

The second approach was the adoption of a new technique, Moire interferometry, to characterize the thin film mechanical properties. This technique, which was applied to thin film substrates for the first time, is sensitive to very small directional changes in tensile properties and will provide a deeper understanding of molecular composite behavior. In Moire interferometry, a grating was applied to the surface of the specimen, and it deformed with the underlying specimen. This specimen grating was a reflection-type phase grating of frequency f ∫ 2. It was generally formed on the specimen by a replication method.

The deformation of a specimen was visualized in terms of a whole-field contour map. Strains were calculated from these whole-field displacement contours. A simple parametric relationship can be easily derived between the fringe orders and displacement fields of the deformed grating.

Corresponding specimen gratings and virtual reference gratings interact to produce the whole-field fringe patterns of U and V, where U and V are displacement components in the x and y directions, respectively. The relationship between displacements and fringe order is $U = (1/f \int) N_x$; $V = (1/f \int) N_y$ N_x is the Moire fringe order at any point in the fringe pattern obtained with the reference grating lines oriented perpendicular to the x axis. N_y is the fringe order taken from the pattern obtained with the reference grating lines oriented perpendicular to the y axis.

Figure 1 demonstrates a fringe pattern obtained from a preliminary testing of rigid-rod thin films under the load of 1.250 N. Using the stress obtained from the load and the area of cross-

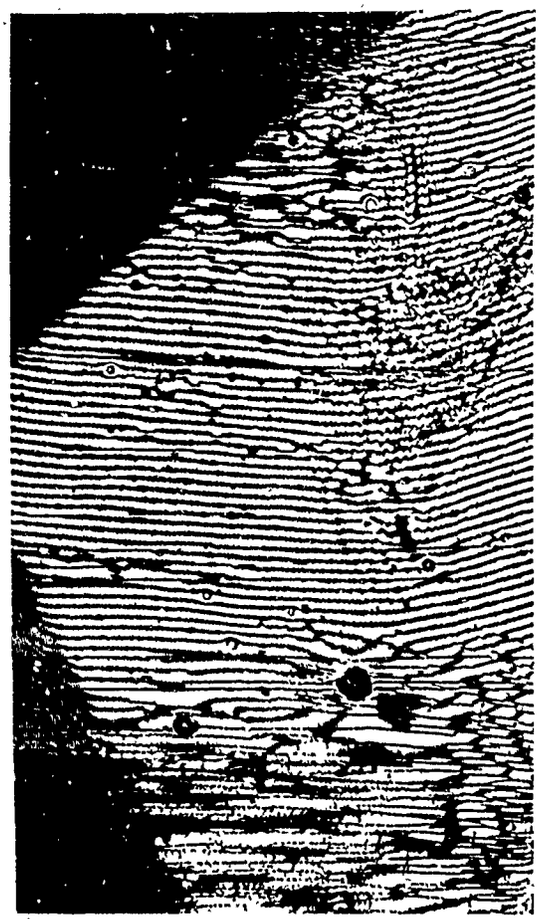


Figure 1
U-Displacement Pattern of Thin Film Specimen

ΔN_x	Δ_x (mm)	f (ℓ/mm)	$E_x(10^{-3})$	$\sigma_x(10^7 Pa)$	E(GPa)
16.2	5.08	2400	1.329	1.094	8.25

Table 2
Young's Modulus Calculations on Polyamic Diethylamide Films

section of the rigid rod thin film, Young's modulus E_{11} was calculated as shown in table 2.

Films thus fabricated will have a high degree of anisotropy, if the rigid rod precursor is converted to a rigid-rod with significant persistence length, and if the rod molecules are aligned unidirectionally.

About twenty specimens made with various concentrations of rigid rod polymer and matrices are tested for measurements of tensile stress-strain relation, Young's moduli (E_{11} and E_{22}), Poisson's ratios (V_{12} and V_{21}), ultimate tensile strength (0_{ult}), and fracture toughness (K_{IC}). Detrimental effects of voids to the strength and failure, or the nonuniformity of the material properties, are characterized by measuring the anomalous deformation fields around voids or material defects.

In summary, within Phase I and in less than one year into Phase II, the feasibility of using a rearrangeable precursor for preparing molecular composites was demonstrated. To do this, development of a novel (and patentable) process for making the necessary precursors was imperative. At the same time, applied new mechanical measurement technology for characterizing molecular composites was conducted. These early successes allow more time to improve the materials and develop well-integrated processing procedures.

Realistically, it will take several more years to develop these materials and processes into commercial products. However, by continuing the effective team work demonstrated so far, the completion of Phase II will place us one giant step closer to an ultra-high performance plastic composite that will compete with metals in demanding applications.

This research was performed by Dr. Terry Brewer and Dr. Tony Flaim of Brewer Science, Inc.; (314) 364-0300. The contract was administered by Dr. Fred Arnold, Wright Research Development Center/MLBP at Wright-Patterson AFB; (513) 255-9160. ■

Distributed Kalman Filter Architectures

Until now the inherent accuracy and fault tolerance of multi sensor navigation systems has been limited by the standard data processing technique known as "Kalman filtering." Heavy computation loads, inability to keep up with high-rate sensor data, and vulnerability to gradual failures have forced designers to resort to various ad hoc "fixes" in some multi-sensor filters. These ad hoc solutions, however, were not always reliable or predictable. They also run the risk of exhibiting poor performance under certain operating conditions.

For these reasons, there has been considerable interest in new optimal filtering methods for decentralized multi-sensor navigation systems. Finding new methods was the primary objective of this project. These methods were to provide improved navigation accuracy, stability, fault tolerance, computational efficiency, and adaptability. Also the advent of parallel processing technology and emphasis on fault tolerant system design encouraged further interest in the development of such systems.

The new distributed Kalman filter (DKF) method is an extension of the class of optimal estimation techniques known as Kalman filters. It is based on a novel information-sharing technique. This technique permits the total system information to be divided (shared) among several local filters. Each of these filters is dedicated to a unique navigation sensor or sensor set, plus a common reference system. New information in the form of sensor measurements is incorporated by the local filters, operating in parallel on separate processors. Periodically, the updated local information is combined by a master filter to obtain the overall best solution. The master filter may then divide and redistribute the total information among the local filters for another round of local processing. A critical aspect of the new method is its technique for sharing the common reference system information among all of the component filters.

Perhaps the new DKF method can best be illustrated by an example. Figure 1 shows a hypothetical but representative multi-sensor aircraft navigation system. The suite of sensors includes: 1) an inertial navigation system (INS) that measures aircraft acceleration and altitude; 2) a Global Positioning System (GPS) receiver that measures range and range-rate to satellites, 3) a synthetic aperture radar (SAR) that measures velocity and position relative to landmarks; and 4) a terrain-aided navigator (TAN) that measures position relative to a stored terrain map.

The new DKF method permits measurements from external sources (GPS, SAR, TAN) to be individually combined with data from the internal source (INS) via separate local filters operating in parallel. The outputs of these local filters are periodically combined by a master filter to generate the best estimate of aircraft position and velocity. The master filter also has the ability to "calibrate" the less accurate sensors via information from the more accurate sensors.

Successfully developed in this project, the DKF method achieves the inherent advantages of distributed navigation systems by means of a major extension to optimal (Kalman) filtering theory. The new information-sharing technique is rigorously correct, yet relatively easy to understand and to implement. It provides distinct advantages over existing methods in terms of: 1) accuracy; 2) processing speed (data throughput); 3) adaptability to changing mission conditions; 4) fault tolerance; and 5) real-time system simplicity. It is generally applicable to other decentralized

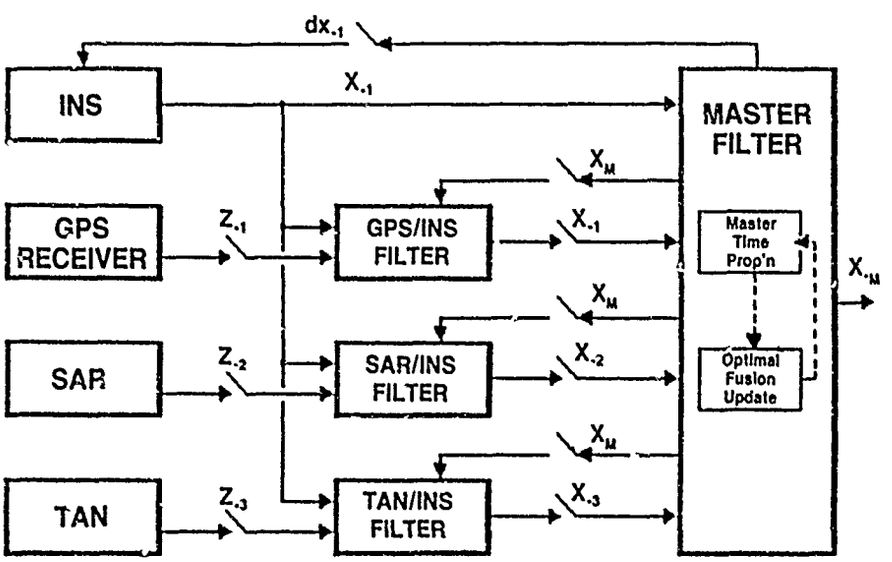


Figure 1
DKF Application to Multi-Sensor Navigation System

sensing and processing systems as well.

DKF methods are optimal in that they provide minimum-error estimates of the system state such as aircraft position and velocity. These filters attempt to remove random errors from the sensor measurements and system dynamics. In doing so, they provide more accurate estimates of the system state. Also, they employ a weighted least squares algorithm for processing new information sequentially, so that estimates of the time-varying system state can be updated whenever new information arrives.

The second advantage is an increased data throughput (or processing speed). It is exhibited in the following three ways. First, the DKF uses parallel processing when multiple computers are available. Second, it breaks up the total estimation problem into a set of small but related estimation problems. (Several small filters run much faster than one large filter.) Lastly, the large master filter can operate at a reduced rate.

The next advantage of using the DKF method is that it improves system adaptability. For example, if a new sensor is added to the suite, local filters for the existing sensors need not be changed. (Some current-generation sensors in off-the-shelf hardware/software packages do not readily admit changes.) However, the master filter can be modified as needed to accommodate the new sensor/filter inputs.

The DKF improvement of fault tolerance is another advantage in two important ways. First, it provides improved fault detection adaptability by testing for faults at both the local and master filter levels. A gradual failure in one sensor tends to accumulate in the associated local filter solution. Eventually, it becomes visible and identifiable when compared to other local filter solutions. (In contrast, a single, standard filter blends all data as it comes in; a gradual failure in one sensor may never stand out.)

The second fault tolerant benefit relates to fault recovery capability. The DKF can be operated in a "no-feedback" mode in which the local filters all run independently, with no feedback of combined information from the master filter. In this mode, bad information from one failed sensor will not be distributed to the other local filters, even if incorporated by the master filter. Since the good local filter solutions remain uncontaminated, a good master solution can quickly be regenerated from them, once the failed sensor and its filter have been isolated. In contrast, a single, standard filter would require a complete restart when the fault was detected, because there would be no practical way to "back out" bad data from its solution.

The fifth and last DKF advantage in real-time system simplicity is derived from the relative independence of its local filter operations and the relatively simple synchronization requirements among the local and master filters. The master filter can sample and combine the local filter outputs at a selectable and adjustable rate; it is not tied to the local sensor output rates, nor to the local filter processing rates. As a result, the sensor subsystem operations need not be physically synchronized; the sensor and local filter outputs need only be properly "time-tagged."

The new DKF method also has several potential applications beyond multi-sensor navigation systems. The method is quite general, and can be applied to most systems that involve optimal estimation in a decentralized, parallel processing environment. Other potential applications include. multi-tracking systems for missile defense, interoperable navigation systems for commercial aircraft, cooperative spacecraft rendezvous navigation, weather tracking from distributed data sources, and geological data processing with distributed sensors.

This research was performed by Dr. Neal A. Carlson of Integrity Systems, Inc., (617) 721-7200. The contract was administered by Michael P. Berarducci, Wright Research Development Center at Wright-Patterson AFB; (513) 255-2302. ■

Combined Holographic-Infrared Inspection of New Materials

Traditional methods for nondestructive testing to assure quality were developed for metallic structures. Methods such as ultrasonics and x-radiography provided very useful information about the soundness of welds, castings, and other metallic assemblies. It also left the inspected product in a usable condition. The value of nondestructive testing to assure that products were manufactured according to specification, or to detect degradation of components in service, is well established.

It was natural to apply these well-proven nondestructive methods for the inspection of new materials, such as laminated composites and bonded assemblies, as these materials began to be used for aerospace, automotive, marine, and other applications. The new materials were attractive in that they provided high strength and low weight, thereby giving opportunities for increased payload and fuel-efficiency. The conventional methods for nondestructive testing of these new materials worked, but improvements were desired in terms of inspection time, cost, applicability to field environment, and signal interpretation.

Investigating the use of a combined holographic infrared inspection method, particularly for application to these new types of materials, was the primary objective in the Phase II program. Holography interferometry is used to detect relative surface displacements on parts. As a part is stressed some relative movement of the surface over an interior defect, such as a delamination, is expected. Infrared imaging is used to detect relative changes in temperature of either the heated surface or the opposite surface. Expected is some surface temperature variation as a result of an interior defect, such as a void. The defect impedes the uniform diffusion of heat through a briefly heated inspection part. In this new combined inspection system, thermal stressing of the part has led to useful signals from both holographic interferometry and infrared imaging. The best methods to apply the thermal excitation and combine the inspection signals were investigated.

Examples of individual inspection results from holographic interferometry and infrared imaging are shown in figures 1 and 2. Figure 1 is a holographic interferogram showing fringe patterns that resulted from impact damage to a fiberglass composite tube. The interferogram was produced by taking a double exposure hologram of the part, with the part stressed between the two holograms. The fringes provided quantitative data about the relative movement of the surface as stress was applied between the holographic views. The pattern in figure 1 shows that the tube surface moved more over the impact damage area (outlined by the circular and narrowing fringe patterns) than over the sound areas of the tube (the straight uniform fringes).

Figure 2 is an infrared image of a composite sample showing the relative temperature distribution after the surface was briefly and uniformly heated. The darker square patterns represent high relative surface temperature areas over internal, deliberately placed flaws. The different grey levels

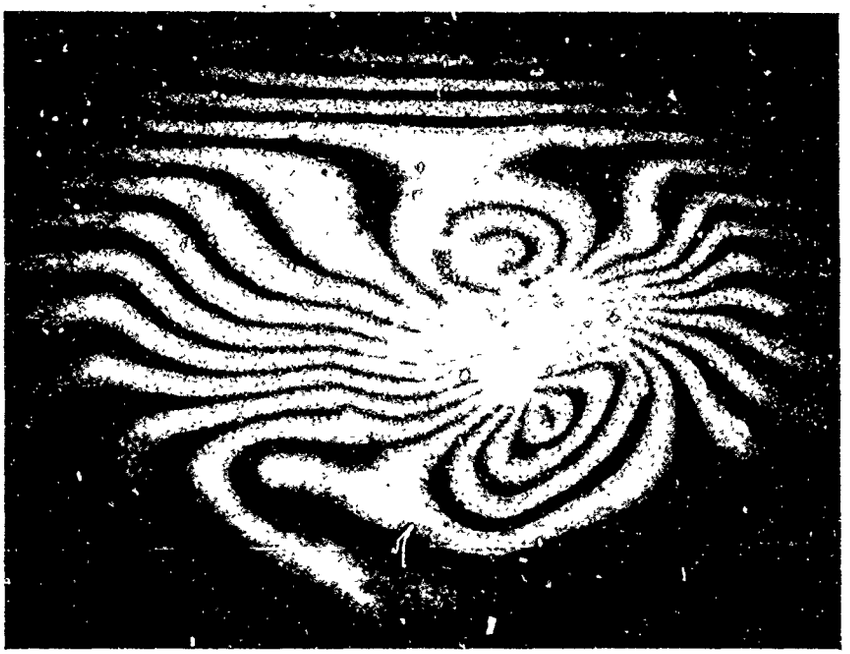


Figure 1
Holographic Interferogram Revealing Impact-Damage

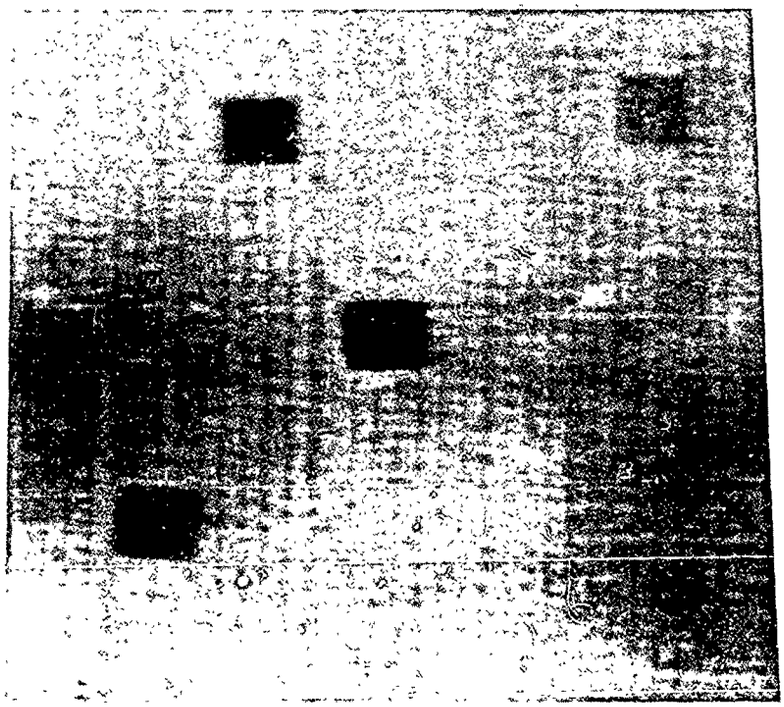


Figure 2
Infrared Image of Purposely Faulted Structure

(surface temperatures) result because of the different depths of the flaws within the laminated structures. Depth of a defect can be determined by the relative surface temperature at a given time and by the relative time after the heating is stopped. The white spots (low temperature) represent honeycomb cells filled with adhesive; the adhesive provides better heat diffusion as compared to an empty cell.

These two images show some of the capabilities of these valuable inspection methods. In many situations signal interpretation of the images is straightforward. Both techniques interrogate a relatively large area (several square feet) in one view; thereby speeding the inspection. There are good prospects for field use of the methods.

All these advantages apply to the combined holographic infrared system under development. The combined inspection system represents some complementary capability, so that one method applies where the other is less effective. For example, holographic interferometry will be less effective for inspecting stiff skin structures that resist relative displacement. Infrared methods may be less effective for the inspection of highly conducting metallic skin assemblies. When used together, the methods provide backup for each other. In addition, quantitative data about surface displacement and relative surface temperature can be used in special cases to determine the strain field within the inspected volume of the part. Thus information would be provided about the defect type, size, and location.

This research was performed by Harold Berger of Industrial Quality, Inc.; (301) 948-0332. The contract was administered by James Holloway, Wright Research Development Center/ MLLP at Wright-Patterson AFB; (513) 255-9797. ■

The Bioextraction of Gallium Ore

In the U.S., known gallium deposits occur in very small concentrations in diverse ore bodies which cannot be economically mined with conventional technology. Therefore, domestic gallium requirements can be met only by importing both ore and competing electronic components.

Bacterial leaching or bioleaching is remarkably well suited for processing the small concentrations of Gallium which occur in manufacture metal tailings and waste streams, and previously inaccessible deposits. Bioleaching has been defined as a hydrometallurgical process for solubilizing metals and separating these metals from their mineral matrices. This approach yields low operating costs, and mitigation of air and water pollution usually associated with conventional mineral recovery methods. In recent years, bioleaching has been applied to the study and development of processes for extraction of copper, uranium, gold, silver, lead, bismuth, cobalt, nickel, magnesium, manganese, titanium, antimony, tin, and zinc.

The role of bacteria in the solubilization of gallium has been the subject of few studies. Recent interest has developed, primarily because gallium is an important strategic metal. New semiconductor devices based on gallium arsenide technology continue to be introduced. Advanced work in electronic applications include light emitting diodes and lasers, which are incorporated into computers, fiber optic telephone systems, and machine controls; all of which use semiconductors.

The bioextraction of metals takes place in two ways: direct or indirect interaction. With indirect interaction, the microorganisms are responsible for generating a reagent that causes solubilization of the metal sulfide, most commonly through oxidation. In direct interaction, the microorganisms attack the metal sulfide directly by oxidizing its insoluble form into the soluble sulfate salt. For example, indirect leaching microbially oxidizes ferrous iron (Fe^{+2}) in acid conditions. This exothermic reaction can be described as:

$$4FeSO_4 + O_2 + 2H_2SO_4 \rightarrow 2Fe_2(SO_4)_3 + 2H_2O$$

The ferric iron (Fe^{+3}) formed (which will remain in solution at the low values of pH) is itself a strong oxidant which abiologically will oxidize more ferrous iron (Fe^{+2}) which serves as a substrate for the bacteria. The process can proceed abiologically, but the rate is greatly increased through the activity of the bacteria. In the case

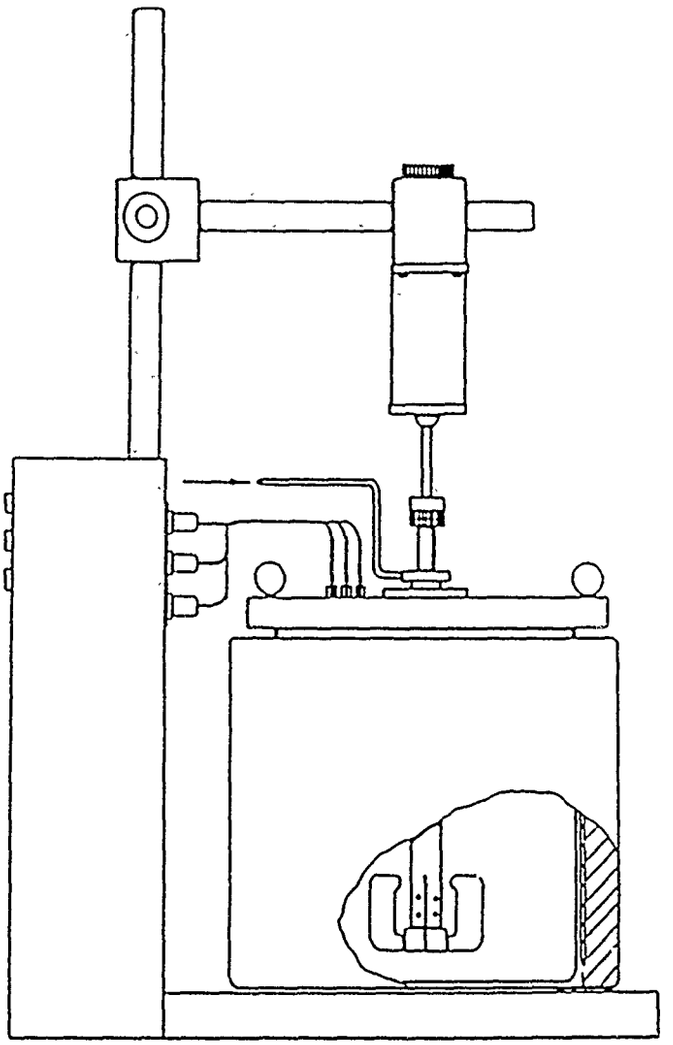


Figure 1
Bioreactor

of continuous oxidation of $FeSO_4$ at 31°C and at a pH of 2.2, *Thiobacillus ferro-oxidans* can oxidize Fe^{+2} at a speed approximately 500,000 times greater than the speed of chemical oxidation.

The Phase I work was carried out on small scale. Bacteria were first hybridized from a hot spring culture found in northern Utah and further acclimated to the St. George Apex Mine gallium ore. All experiments were conducted in incubated flasks containing 100 grams of the ball milled ore, 5 ml of the resulting bacterial culture, and 95 ml of 1.8 pH media. Tests were run at three temperatures. 25°, 37°, and 75°C maintaining pH at 1.8. Distilled water was added periodically to compensate for water loss due to evaporation. The solutions were mechanically agitated and aerated. Sulfuric acid buffering with an occasional ferrous sulfate addition was required due to a consistent buffering to pH 4. Sterilized controls were maintained for all. The liquor, the leach residue, and pH were analyzed. The variables which were studied included: metal tolerance, pH, nutrients, oxygen and carbon dioxide, temperature, mineralogy, and particle size.

In the Phase II work, a reactor was developed as seen schematically in figure 1. The bioreactor vessels were designed for three stages in series, as depicted in figure 2, to simulate true process variables. Each vessel was aggitated and aerated with a carbon dioxide air mix and contained five liters of material. Each vessel had a separate temperature control and the system was methodically monitored for water level, pH, dissolved oxygen, and oxygen uptake.

Each reactor was initially seeded with a 10 percent bacterial culture and acclimated on a 10 percent solids raw material input. The optimal leaching conditions (such as initial 1.8 pH), substrate and nutrient microbial requirements, and aeration flow rate were maintained throughout. A portion of the aliquot was saved weekly to track the viability of the organisms and leaching rate.

Through experimentation, we found that the bacteria must be in intimate contact with the mineral they metabolize. The nature of the ore, the mineral composition, the concentration of sulfides, the presence of absorbents, and the conditions of the medium in which the process of oxidation takes place all determined the degree of bio-solubilization. The speed of bacterial oxidation was increased by means of aeration of the solution and addition of nutrients. It was also determined that the speed of bacterial oxidation dropped sharply due to low temperature. Without bacteria, oxidation did not occur.

There is a delicate balance and concomitant reaction between sulfur, iron, and arsenic in the gallium bioleach system. All three are required for organism growth and ore solubilization. The sulfur can be used as flowers of sulfur, sulfuric acid or as a sulfide, as in pyrite (iron sulfide) or arsenopyrite (arsenic/iron sulfide). Both the iron (as ferric)

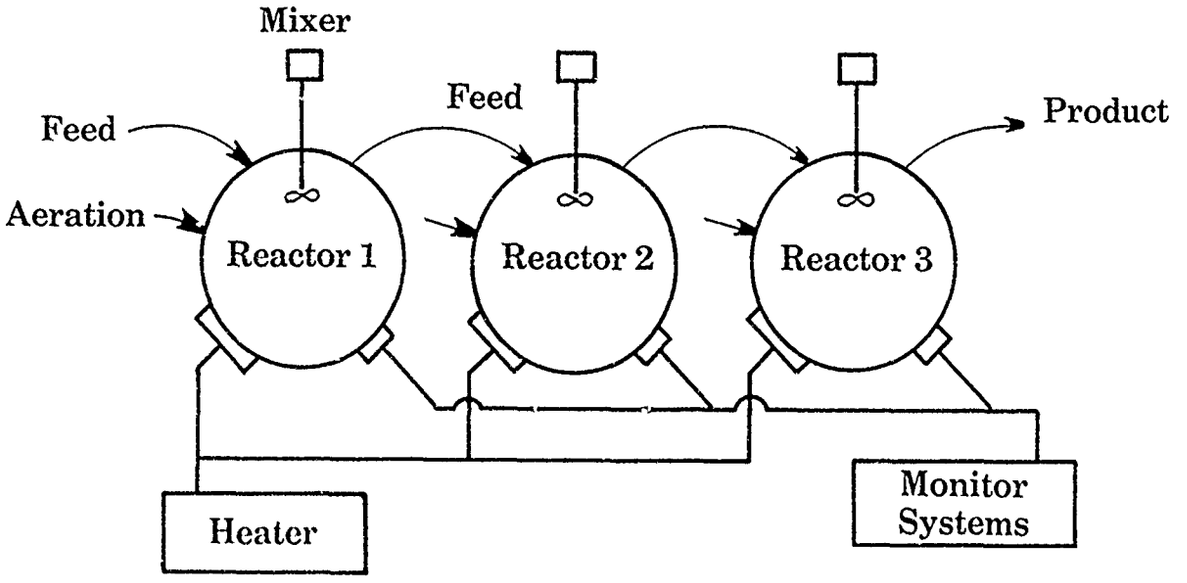


Figure 2
Three-Stage Bioreactor

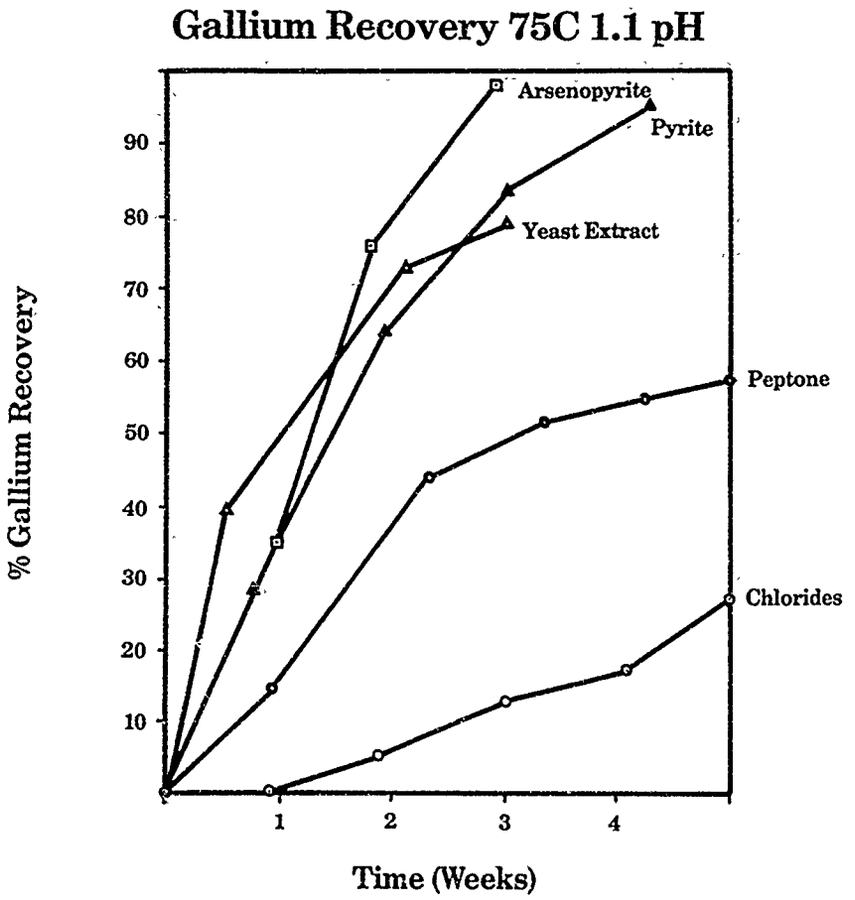


Figure 3
Gallium Bioleach Results

and the arsenic have shown to be best assimilated through the deterioration of arsenopyrite, but both can be used in other forms.

Arsenic di , tri , and pentasulfide and phosphide have been used to improve growth and bioleaching. Chloride, alone or mixed with arsenic (arsenic trichloride), iron (ferric chloride), and/or sulfur (sulfur mono and dichloride and flowers with HCl) have been found to inhibit, often kill, the organism. Oxalates, carbonates, and ferrocyanides did not encourage solubilization.

Test results have also shown that arsenic levels of 15 percent can be tolerated and chlorides must be augmented with iron or arsenic sulfide. Peptone, B vitamins, yeast, malt, and beef extract tests have shown accelerated culture growth. Extracts and peptone have been good supplements, but the expense was prohibitive. In addition, the growth and leaching peak was short lived and culture death was imminent. Amino acid addition experiments have been conducted with important results. Carbon dioxide addition mixed with oxygen, in very small flow rates, improved solubilization. Work continues on these and other parameters.

When the process-stable and scaled-parameter study is complete, semi-continuous feed and withdrawal will be initiated. Daily aliquots will be removed from each reactor, starting with the third vessel at a low removal rate of 20 cc per day. The aliquot from the first reactor will be placed into the second, the second into the third. The centrifuged liquor from the third reactor will be used as a conditioning agent for the ore being placed into the first vessel.

As a function of in-series set-up, the extent of oxidation will be different in each vessel. Equilibrium will be established over time. If it is determined that critical information can be gained, a fully continuous set-up will be installed by placing peristaltic pumps into the circuit. However, in the long run, pumping will be less cost efficient. Figure 3 shows the most recent gallium bioleach results at 75°C and 1.1 pH.

With the development of new electronic, medical, and composite materials, the U.S. demand for gallium is expected to increase at an average annual rate of approximately 7 percent through 1990. New research and development continues on the properties, fabrication techniques, and uses of gallium compounds. It is expected that the United States may well need the accessibility bioleaching affords to maintain domestic stockpiles, keep up with projected domestic demand, and successfully compete with improved international markets. There is, therefore, a distinct need for this efficient, domestic, cost effective method of gallium recovery.

This research was performed by Gail Bowers-Irons of Technical Research Associates, (801) 582-8080. The contract was administered by Dr. Fred Hedberg, Wright Research Development Center/ MLBC at Wright-Patterson AFB; (513) 255-9065. ■

Non-Destructive Evaluation of Thin-Shelled Structures

The principle of laminography is similar to the basis of CAT (Computer-Aided Tomography, also referred to as Computed Tomography or CT) scanners used widely in the medical field today. Both processes produce digital images of thin planar sections within an object and both require an x-ray source, a detection system, and data acquisition and processing capabilities. The basic difference between Computed Tomography and Laminography is that CT provides information regarding the cross-sectional structure of an object, whereas laminography provides information about its longitudinal structure. Both methods provide information that is complementary, but distinct. Of the two approaches, laminography appears to offer the better inspection capability for thin-walled structures. This is because laminography provides images of layers within and concentric to the natural shape of the object. This is a much more appropriate (and intuitive) presentation of the internal structure than ring-like images of cylindrical or conical objects produced by CAT-scans.

Laminography is based on digital radiography and classical tomography. Digital radiography, which is directly related to classical film-based radiography, is a relatively new imaging modality in which suitable solid-state detectors (rather than film) record the spatial intensity variations of x-rays that have traversed an object. The corresponding images are digitally prepared by the computer from the radiographic projection data and are visually presented on a video monitor or other high-resolution output device. The major limitation of digital radiography, as with all standard radiography techniques, is that a two-dimensional representation of a three-dimensional object is produced. The resulting superposition of structure restricts the interpretation of the image.

Classical tomography, on the other hand, is a well-established x-ray technique first introduced in the early 1920's. With this method, an x-ray source and film cassette move synchronously and contin uously in opposite directions about a fulcrum. The image plane, called the tomographic plane, is parallel to the motion and passes through the fulcrum. An image of this plane is produced on the film because structure above or below the tomographic plane is blurred by the motion. The structure within the tomographic plane is stationary with respect to the focal plane and thus remains in "focus". By changing the level of the fulcrum, a series of parallel sections, laminograms, can be sequentially obtained. Care must be taken to ensure that each exposure is sufficiently intense to provide adequate exposure. A new film cassette must be used for each plane to be imaged.

Laminography weds classical film base tomography and digital radiography by retaining the basic concept of focal plane imaging. It replaces the film cassette with a suitable array of radiation detectors whose outputs are monitored electronically. Some type of parallax producing motion between the object and the

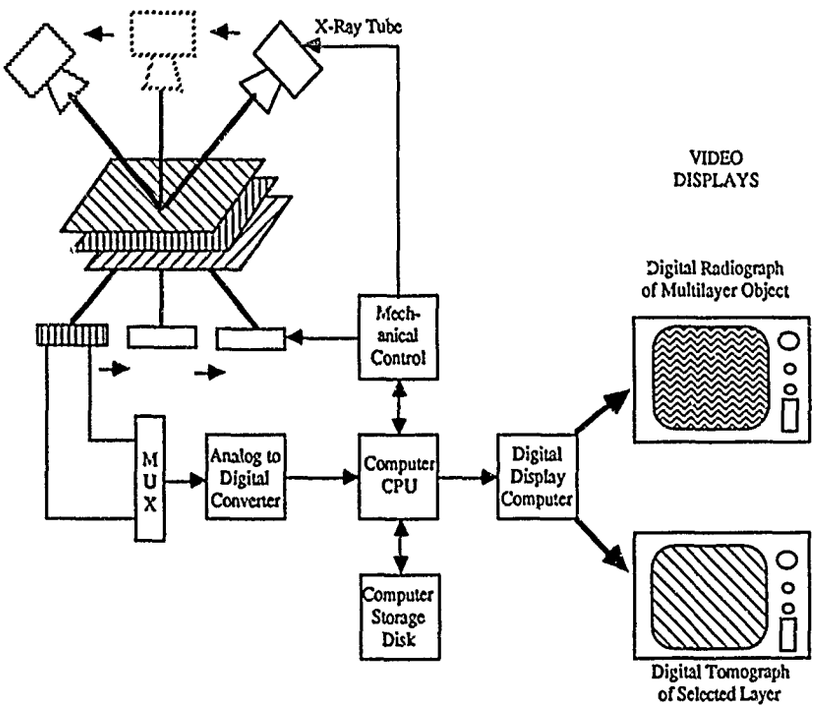
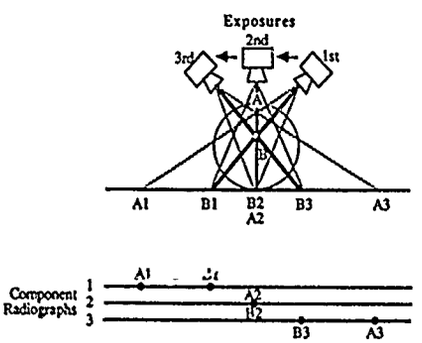


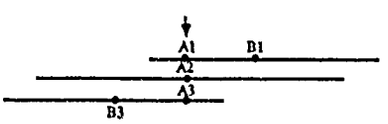
Figure 1
Schematic of Digital Tomography Procedure

detector must still be maintained, but the mechanical motions demanded by classical film-based tomographic systems are greatly relaxed. This is because laminography is a two-step process. First, a complete set of digital radiographs, taken at a sequence of evenly-spaced angles of view, are measured and stored. Secondly, the focal plane integration, which is performed classically by the film, is carried out after the scan by the computer from the stored or component radiographs.

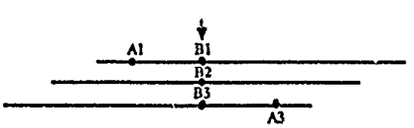
Computer processing of these component radiographs permits the reconstruction and visualization of structure in the tomographic plane. Figure 1 outlines this procedure. The component radiographs are processed in sequence, synthesized into a tomographic image residing in memory, and then displayed on a video monitor. Laminography, unlike its classical counterpart, enables many planes to be arbitrarily viewed with the data obtained from just a single exposure sequence, thereby reducing measurement time. As can be seen in figure 2, the plane of focus is selectable, depending only on the appropriate manipulation of the recorded data. This concept can be further generalized to include the visualization not only of simple planar sections, but also interior surfaces of arbitrary shapes. This gives laminography the ability to reconstruct arbitrary structural surfaces from a single sequence. This is of major significance for the examination of thin cylindrical and/or conical structures for which planar radiographic images are simply not appropriate.



a) Scanner Motion



b) Relative Displacement of Component Radiographs for Point A Focus



c) Relative Displacement of Component Radiographs for Point B Focus

Figure 2
Schematic of Data Imaging for Laminography

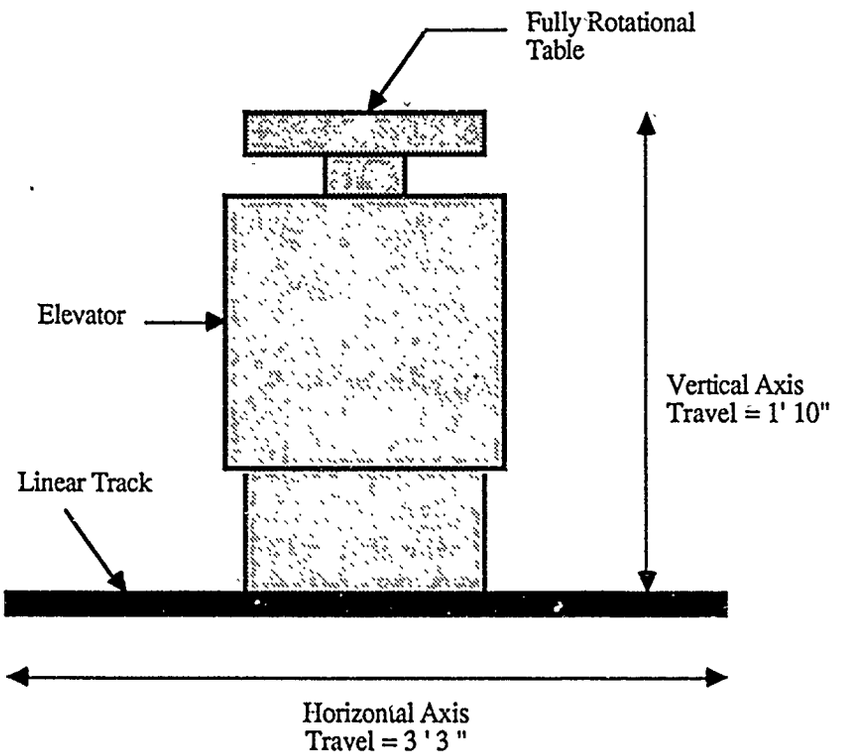


Figure 3
Laminography Scanner Handling System

The design for the laminography x-ray scanner built for this program was based on the design of current digital radiography equipment. The hardware design is a critical consideration for laminography since precise motion of the scanner must be guaranteed. The design called for horizontal, vertical, and rotational motion of the object to be scanned. In addition, the handling system was required to perform these motions with a great deal of accuracy. The final design provided for approximately three and one-half feet of horizontal motion, slightly less than two feet of vertical motion, and full rotational motion. A schematic of the handling system design is shown in figure 3.

The x-ray source is placed on one side of the handling system. The detector package is placed on the opposite side. The x-ray source sends out a wide beam which is

collimated by adjustable lead plates. The detector package also has adjustable lead collimators. Collimation of the beam creates a relatively thin beam profile which is desirable for digital radiography. X-rays, unlike light, do not reflect well and so lead is used to absorb unwanted portions of the x-ray beam creating a "collimated" beam of the appropriate size. Behind the detector collimators lie the detectors and the electronics, which read and digitize the measured detector data. The detectors and the electronics are enclosed so that the entire detector package can be environmentally controlled to reduce electronic noise. A schematic of the x-ray source collimation design is shown in figure 4 and the detector package is shown in figure 5.

The x-ray source, the handling system, and the detector package are integrated to form a complete laminography scan system. The operator has a computer terminal screen, a keyboard to type in commands, and a color display monitor for image presentation. The computer operating system is complete with the necessary laminography software to process the raw data.

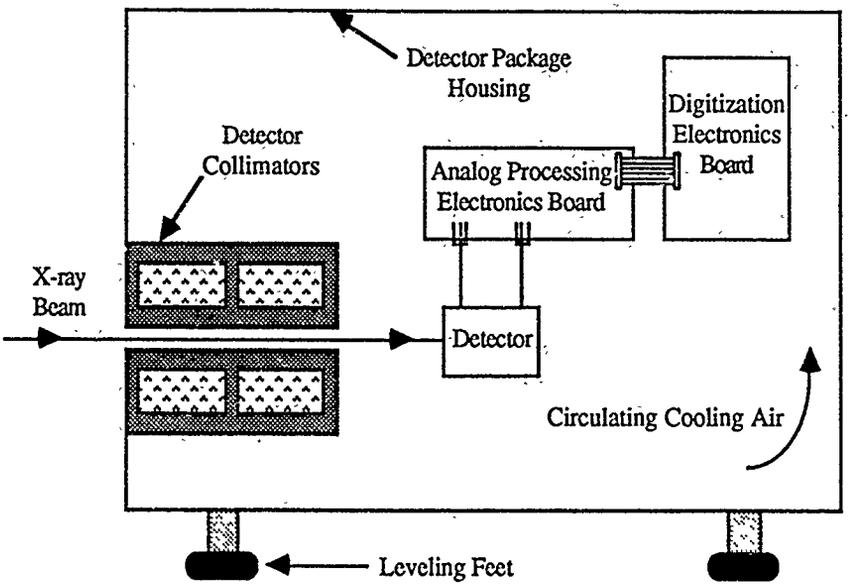


Figure 5
Side View of Detector Package

To demonstrate the capability of the system, a filament wound graphite composite cylinder was scanned. The entire set of digital radiographs was processed to obtain the laminography. The structure of the filament wound cylinder was clearly seen with the individual fiber strands running in a pattern typical of this object.

The application of laminography to the non-destructive inspection of thin-shelled structures is a major step forward in developing cost-effective means to insure the quality of increasingly complex objects. Laminography inspection of parts such as solid rocket motor components allows for flaw detection earlier in the manufacturing process which ultimately can save millions of dollars in operational costs. Bad parts can be scrapped as soon as a manufacturing flaw is discovered, rather than completing assembly with a bad part, only to later discover that it must be 'unassembled'. Effective non destructive evaluation of these parts will also better insure the reliability of inspected components once they are put into use. Overall, laminography will provide a quick and efficient means to inspect many critical military components. Laminography can also be applied to a wide variety of commercial uses, where inspection of thin-walled structures is needed.

This research was performed by James H. Stanley of Aracor; (408) 733-7780. The contract was administered by Thomas Moran, Wright Research Development Center/MLLP at Wright-Patterson AFB; (513) 255-9806. ■

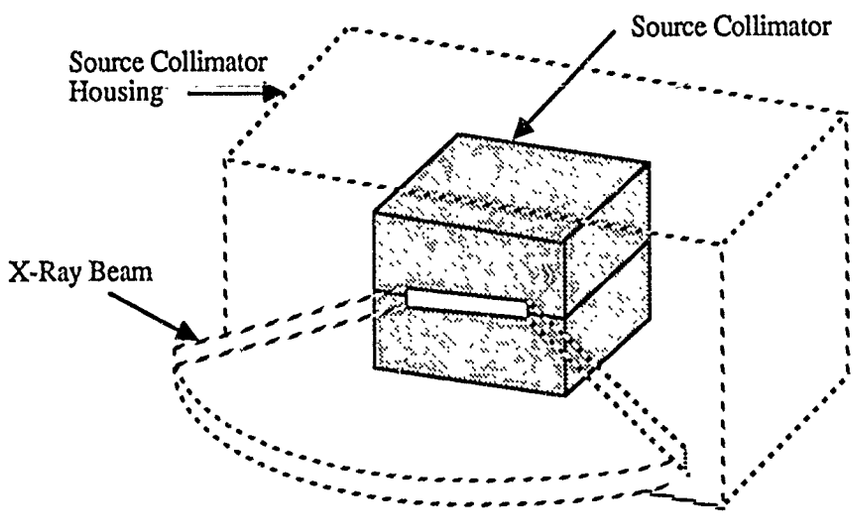


Figure 4
X-ray Source Collimators

Numerical Simulation of Liquid Encapsulated Czochralski Growth of Gallium Arsenide Crystal Under an Applied Magnetic Field

The rapidly growing use of gallium arsenide (GaAs) in discrete and integrated circuits for microwave, opto-electronic, and digital applications has created a high demand for single-crystal substrates of this material. Thermal stability, low dislocation density, and a uniformly high electron mobility were essential to ensure high-performance circuits with acceptable yields. Dislocations in the substrate, for example, reduced the lifetime of laser diodes and affected the uniformity of the FET threshold voltage. Although many melt and solution growth techniques have been used for some years to prepare bulk gallium arsenide crystals, the reproducible automated growth and fabrication of large-diameter, high-quality material is still in an evolutionary state.

The most widely used technique today is the Liquid Encapsulated Czochralski (LEC) method, illustrated in figure 1. The basic principle of growing a single crystal by the LEC method is the following. A crucible is initially filled with presynthesized GaAs compound. Thermal energy is supplied by a heater surrounding the crucible, thereby raising the temperature of the compound above its melting temperature. A seed crystal, at the end of a rod, is then dipped into the melt and, after appropriate start-up procedures, slowly withdrawn from the melt. To prevent the escape of arsenic during the growth, a molten boric oxide layer combined with a nitrogen overpressure is used. The encapsulant liquid must be pure, chemically inert, lower melting, and lower in vapor pressure than GaAs.

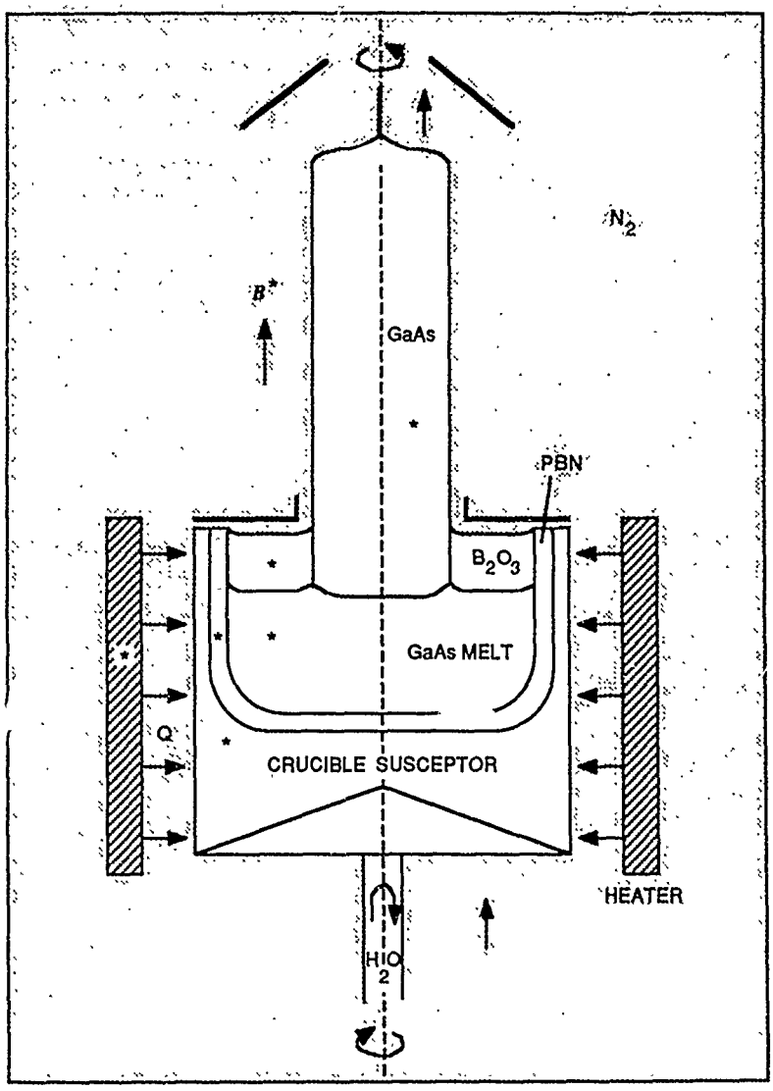


Figure 1
Magnetic Liquid Encapsulated Czochralski System

The preparation of large-diameter, high-quality single GaAs crystals using the LEC method requires both optimum thermal configuration and optimum growth conditions. There are three steps to achieve the optimum configuration and growth conditions: 1) the development of a fundamental understanding of those factors that influence the thermal-hydrodynamic characteristics of a LEC system; 2) the development of computational algorithms to mimic this understanding; and 3) the implementation of real time process control during crystal

growth.

The most efficient and economical approach to study the LEC system was to perform numerical simulations for the growth system. One advantage of using numerical simulations was that various growth conditions can be tested and studied at a small fraction of the time and cost required for laboratory implementation.

Heat transfer characteristics of the LEC system included: 1) heat transport in the melt, crystal, encapsulant and crucible; and 2) heat transfer from the above phases to the ambient, etc. Heat transport in the melt phase, encapsulant, and nitrogen gas were also affected by the hydrodynamics of its phase. The motion of the fluid phases (both melt and encapsulant phases) was induced by three mechanisms. forced, natural, and Marangoni convections. Forced convection is caused by the rotation of the crystal and/or crucible. Natural convection is induced by density variations in the fluid phase. The variation of density is due to nonuniform temperature in the fluid. Marangoni convection is induced by surface tension variation along the fluid-fluid interface due to nonuniform temperature. These convective processes affect the heat transport of the entire LEC system, and thus have a substantial impact on the formation of thermal stresses in the grown crystal. The heat transfer characteristics of the nitrogen gas were also important since it affected the amount of heat loss from the crystal to the surrounding gas.

In addition to the complicated thermal-hydrodynamic characteristics of the system, the time history (kinematics) of the growth process also played an important role in determining the source of defects, impurities, thermal stresses, etc., in the grown crystal. The kinematics of the growth process included the transient thermal-hydrodynamic behavior of the phases and the time dependent variation of: shape of the melt crystal interface, menisci, crystal diameter; melt volume, and vertical location of the crucible. Other externally applied conditions, e.g., a magnetic field,

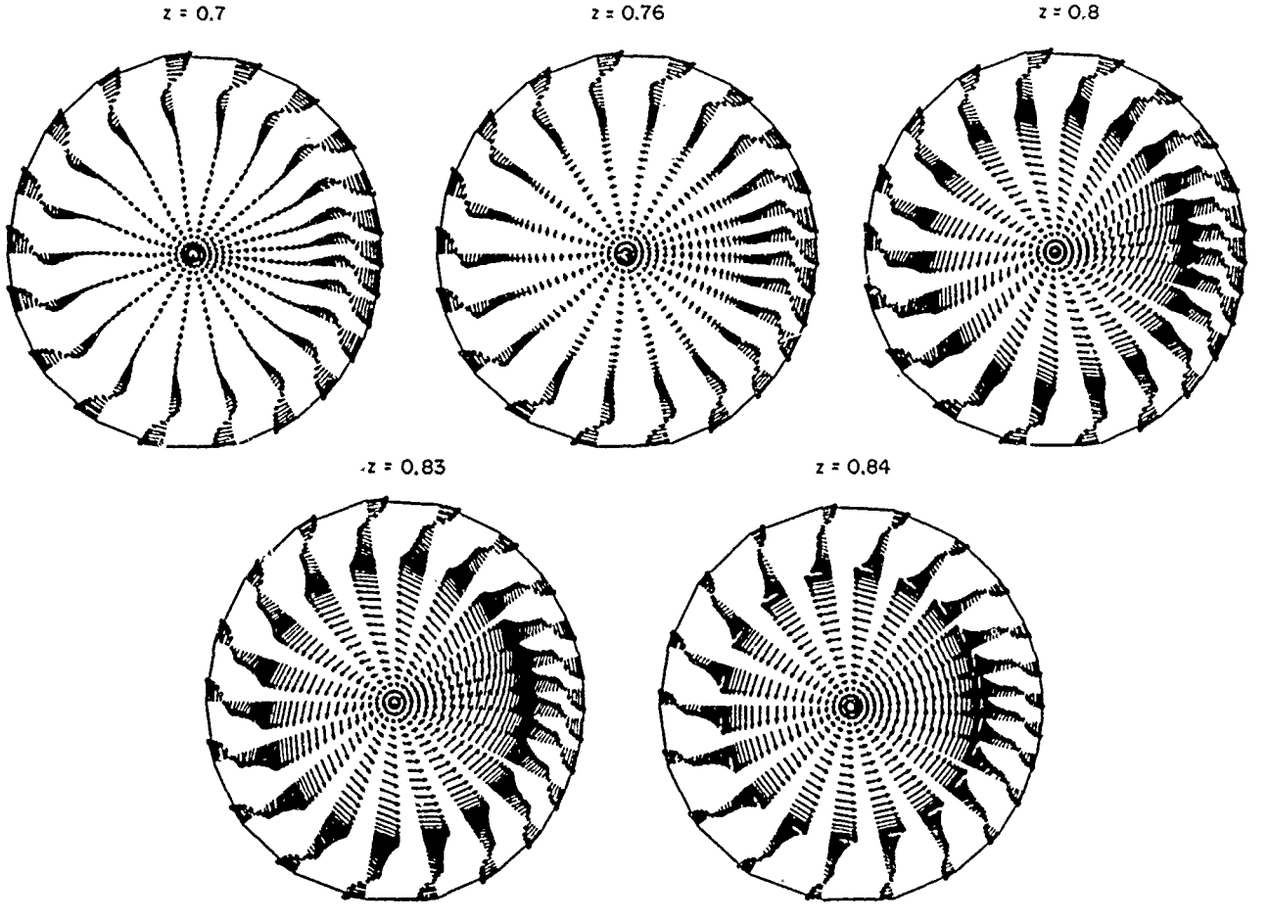


Figure 2
Velocity Field at Different Horizontal Planes

will also affect the quality and reproducibility of the grown crystal.

To perform numerical simulations, mathematical equations based on conservation laws for mass, momentum, and energy were used for the melt and encapsulant. Only conservation of energy was needed for the crystal and crucible. The solutions of these equations for each component were not independent of each other, but rather coupled. Each element was coupled through thermal and/or dynamic conditions along the contact surfaces. These conditions were usually nonlinear, and thus made the solution algorithm complicated. In addition, the shapes of the melt-encapsulant and encapsulant-gas interfaces were not known a priori and needed to be determined along with the solutions from the melt and encapsulant. Since the time-history of the LEC system was important to the quality of the outcoming crystal, the current numerical algorithm also included the transient effects of the system.

Preliminary results from the Phase I program have found that natural convection inside the melt phase was strongly suppressed by the magnetic field. This resulted in a more uniform temperature LEC system. The amount of heat transported by the liquid encapsulant to the nitrogen gas was shown to have an important influence on the temperature distribution of the melt, and consequently have influence on the thermal stresses on the grown crystal. As a demonstration of the numerical simulations, figure 2 shows the velocity field for different vertical planes from one bench-mark calculation. It can be seen that the side wall (crucible) is rotating in a different direction as the crystal surface. The crystal surface touches the melt at z = 0.84. The velocities of the melt in the horizontal planes decrease in a short vertical distance.

At present, predictive capabilities using detailed simulation are being developed and validated with data available from a current crystal growing chamber. The Phase II study provides important understanding of the thermal-hydrodynamic characteristics of the LEC system. This is essential to achieve the optimum growth conditions for growing a zero dislocation GaAs crystal. The numerical capability can provide a cost effective design aid for state-of-the-art growth of high quality gallium arsenide single crystals, thereby enhancing the Air Force goals of reliable high quality electronic devices.

This research was performed by Drs. Y. T. Chan and Harold L. Grubin of Scientific Research Associates, Inc.; (203) 659-0333. The contract was administered by Capt. Greg Peisert, Wright Research Development Center at Wright-Patterson AFB; (513) 255-4474. ■

Failure Mechanisms in Composite Turbine Blades

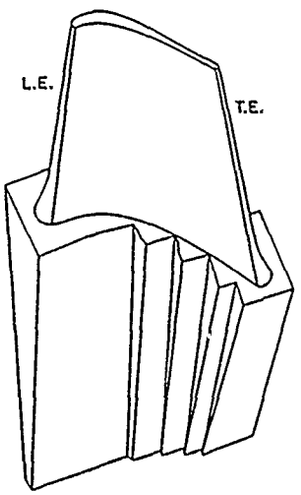
In order to take advantage of their superior mechanical properties, woven fabric composites have been considered for use in turbine engine applications. Specifically, composite lamination construction was employed in the fabrication of experimental turbine rotors. The rotor was built by lamination of woven fabric reinforced layers. These layers were stacked in planes normal to the axis of rotation and subsequently machined to finished dimensions as shown in figure 1.

The purpose of this research was to develop an approximate model to describe the layer-by-layer distribution of the stresses in blades of the rotor and the hub. The present model was restricted to the effect of pure rotation. Such a model was needed to define the ultimate capacity of the structure, as well as to examine the influence of fabric orientation and stacking sequence on the elastic response. In this way, the material and geometric parameters could be adjusted to yield improvements in blade performance and to establish realistic safety factors. A typical blade is displayed in figure 2, where the orientation of the lamination planes and the axis of rotation, x, are also defined.

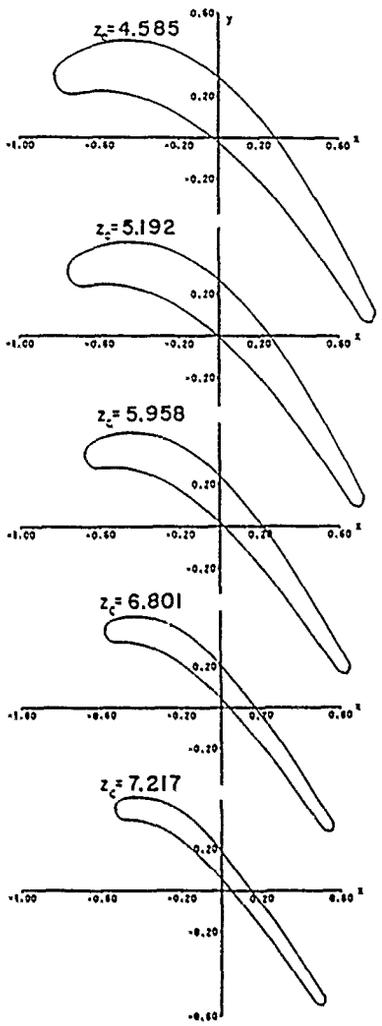
It is debatable whether the composite blade configuration belongs to a novel class of laminate geometric form which defies traditional modeling approaches that depend on classical lamination theory (CLT). In fact, even the effective (or overall) stiffness properties of such a laminate may differ drastically from the predictions given by CLT. These observations stem from the magnitude of the width-to-thickness aspect ratio, which approaches zero in the blades being studied.

There were three different aspects to the proposed problem: 1) stress analysis of the structural component; 2) micromechanical properties and failure mechanisms prediction; and 3) experimental validation. Currently, research is being pursued in each of the three areas.

Detailed treatment of the optimal layer orientations and stacking sequence within a composite turbine blade required the use of approximate modeling techniques. Such approximate methods were needed because of the complexities associated with the large number of layers and the geometric configuration of a twisted blade. Two models have been developed and may be regarded as first approximations to this difficult class of boundary value problems in the theory of elasticity. Each model was based



Blade Configuration



Blade Cross-section at Different z_c's

Figure 1
Rotor Blade Configuration and Cross-Sections

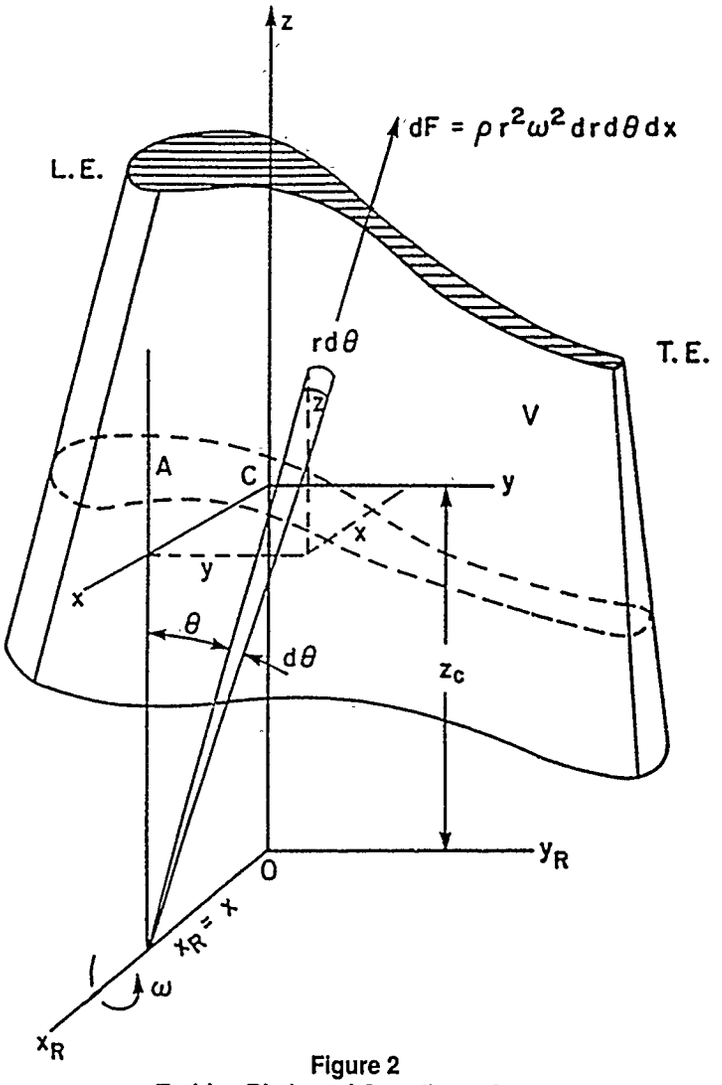


Figure 2
Turbine Blade and Coordinate System

upon an assumed strain field while only one was able to recognize the shear extension coupling characteristics of "off-axis" layers in the xyz coordinate system.

These models can serve as the basis for estimating the strength corresponding to particular blade geometry and layer orientation parameters. This in turn defines an experimental configuration to examine the quality of the models. In addition to these two models for blade analysis, two models for hub analysis are being developed. These models are based upon radial orthotropic nature of the hub. Computer algorithms developed for all aspects of the project were developed for IBM PC and Apple Macintosh compu ters. For stress analysis of turbine blades, a code called "TURBLADE" was developed; for material property evaluation, "PROFAC"; and for hub analysis, "CHAN."

An interesting observation has been made regarding the class of laminates considered, i.e., those possessing very small values of width to thickness ratio. In such cases, the width was insufficient to promote the appropriate stress transfer mechanism necessary to develop the stress distribution given by classical lamination theory. Aside from the stress prediction, even the effective laminate properties may differ from those given by classical lamination theory. These points were demonstrated by the examination of a similar class of boundary value problems well known in composite mechanics literature. An appropriate example must be the free edge problem in laminate elasticity, as the width-to-thickness ratio approaches zero.

Three specific example problems were solved utilizing realistic material properties to demonstrate the feasibility of the use of laminated construction in turbine blade applications. In one of the problems, the blade lamination configuration currently used in the industry for experimental purposes was considered. In the other two examples, lamination configurations showing a marked difference in strength ratios of the blades between the first blade and the other two blades were studied.

The next step was to validate the assumptions considered and the results of the models. The models are modified to include the thermal effects, blade-hub interaction, and coating and transverse loading. The modifications are then implemented in the codes. This work contains a new innovative technique of analysis of composite turbine blades. Because of the simple nature of the method and complicated configuration of the structural component, its application will help aircraft industries to design optimum performance composite turbine blades.

This research was performed by Som R. Soni, S. Chandrashekara, and Mr. U. Santhosh of AdTech Systems Research, Inc., (513) 426 3329. The contract was administered by Howard Brown, Wright Research Development Center, MLBC at Wright Patterson AFB; (513) 255-9070. ■

Microencapsulated Phase Change Materials for Enhanced Heat Transport and Storage in Electronic Systems

The thermal management of energy transport and storage in many avionics or spacecraft electronic systems is vital because of two important factors. First, there is a significant increase in the intensity and frequency of heating loads; and second, there is the growing need to minimize the weight and volume of systems. Without provisions for additional energy transport or storage, the heating and cooling systems must be designed to satisfy maximum peak thermal loads. The systems have considerable idle capacity which often remains unused for much of the time. In addition to higher cost, the penalty for such "over-design" in systems is additional weight and volume.

Various methods for improved thermal management of both electronic and mechanical systems have been developed which use novel microencapsulated phase change materials (PCMs). Almost all materials absorb a large quantity of heat (heat of fusion) when they melt from a solid into a liquid. They absorb an even larger thermal energy when they boil from a liquid into a gas (heat of vaporization).

Some materials, however, require more energy than others. These materials are commonly referred to as good phase change materials (PCMs) and can be used to store large quantities of heat or thermal energy. At a material's solid-to-liquid transition or melting point, the change in volume is significantly less than that at the boiling point. Also, the heat of fusion can be quite large for some materials. So, when these materials are contained or encapsulated, they can be made to absorb or release large quantities of heat without leaking into or contaminating their surroundings.

In this program, a number of PCMs have been successfully microencapsulated into micron-sized particles. Figure 1 depicts a spherical microencapsulated PCM particle. The size of these particles facilitates their being mixed into powders and molded compounds. It also enables the particles to be suspended within two-component fluids or circulated in slurries. Figure 2 illustrates a slurry of microencapsulated PCMs as photographed with an electron scanning microscope.

The diameter of the microencapsulated PCM particles range from one to several hundred microns; the wall thicknesses of the particles range from less than a micron to several microns. The center core of the PCM particles can be selected from a variety of materials to melt at different temperatures. The surrounding shell serves to contain the melted core material, preventing its undesirable mixing with the carrier fluid or contact with other sensitive materials. Heat can then be stored during melting at the material's endotherm and released as it freezes at its exotherm.

When passively used in a powder, paste, or molded compound, the microencapsulated PCM materials can provide significantly enhanced thermal storage and stabilization. Microencapsulated PCM powders have been supplied to government contractors for the purpose of evaluation. Contractors will assess PCM's potential for thermal stabilization of inertial guidance systems as well as the enhanced cooling of electronic components.

Microencapsulated PCMs have been developed to provide advantages for either critical weight or critical volume situations. Powdered PCMs have been mixed into substrates in order to permit enhanced thermal

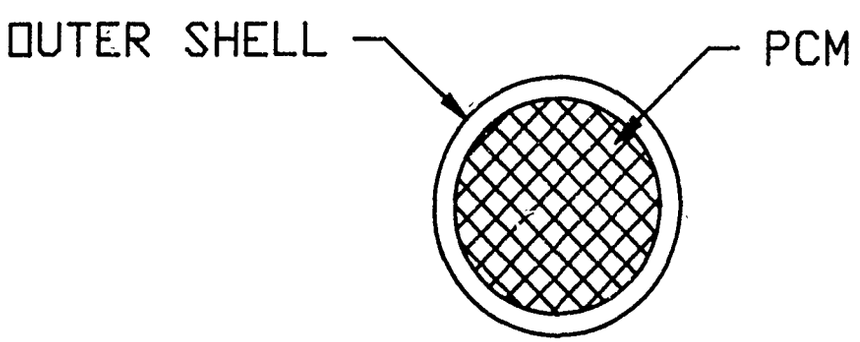


Figure 1
Microencapsulated Phase Change Material Particles

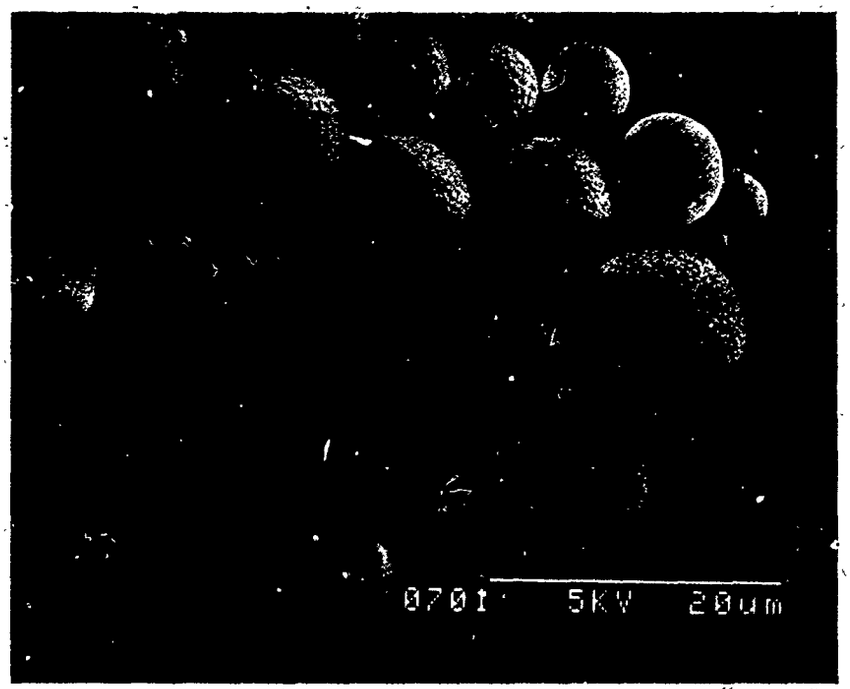


Figure 2
Scanning Electron Micrograph of PCM Microcapsules

storage within moldable compounds or structures such as heat sinks. Laboratory tests have shown that electronic components remain cooler for significantly longer periods of time when molded within PCM-filled compounds. It is anticipated that such PCM-filled compounds will be useful for absorbing transient thermal surges or pulses produced by high-powered electronics. In addition, flexible thermal barriers with enhanced heat storage characteristics were fabricated and tested using PCM compounds between multiple layers of foil blankets. In another Air Force SBIR program, microencapsulated PCMs were successfully incorporated within spun textile fibers to improve their thermal capacitance by 1000 percent.

A circulating two-component PCM slurry testbed loop with an in-line thermal capacitor for enhanced thermal storage is illustrated in figure 3. When the microencapsulated PCM particles are slurried in a compatible carrier fluid, they can provide significantly enhanced active cooling or heating, if circulated in an optimal manner. This permits practically all the heat to be transported in a latent (heat of fusion) mode rather than a sensible one that requires a temperature difference. Seeding a fluid with the novel micron-sized particles in the proper concentration also permits it to be circulated without a severe pumping power penalty. There have been reductions up to 90 percent in the required pumping power with microencapsulated PCM slurries.

Capsule wall materials were developed to be compatible with both water and synthetic fluids such as silicone oils. The fatigue strength of the wall materials has been improved to permit its circulation for tens of thousands of thermal cycles (continued melting and refreezing). An ancillary device was also developed to detect and filter broken capsules from a circulating stream.

Additives were implemented that both improve the suspension of the particles, as well as reduce the required pumping power to circulate the slurry. Other additives have been created that insure the reproducible nucleation of the melted core material of the microencapsulated PCMs.

If the PCM two-component fluid is operated in an optimal manner, the thermal capcitance or heat storage in the PCM-filled slurry effectively increased more than 50 times that for the base fluid; i.e.,the effective Cp of the fluid has increased by as much as 5,000 percent. Likewise, the heat transfer coefficient has improved from 50 to 100 percent over that of the base fluid under the same conditions. In addition, unlike other systems in which higher heat transport is accompanied by larger temperature differences between the heat source and the heat sink, the temperature difference across a circulating loop of microencapsulated PCMs is significantly lower. The closed loop system becomes practically isothermal. This can be of great significance to thermally sensitive systems such as electronics or optical components.

The carrier fluids in the active loops can be aqueous, non-aqueous, or even a liquid metal. In this program, materials were designed for their compatibility with both synthetic fluids and electronic components. The core materials have included a number of paraffin hydrocarbons, as well

as both metals and metal alloys. The encapsulant shells can be either polymers or metals. In Phase II the emphasis has been on the cooling of electronic systems over a range of 25°C to 68°C. Materials have also been developed for other programs that can extend the temperature range from below 0°C to well above 1000°C.

This program has included the development of a number of accessory devices including. 1) in-line thermal capacitors that permit more stable operation of the active systems during thermal surges; 2) a quick disconnect fluids couple; and 3) a low-flowrate slurry flowmeter. The in-line thermal capacitor was designed to impose a minimum pressure drop across itself while permitting the maximum absorption of high transient heat loads. This facilitates the design of efficient thermal management systems around an average heat load rather than a peak load. PCM slurry cooling systems are much smaller in volume, lighter in weight, and lower in pumping power requirements.

The quick-disconnect thermal connector is essentially a compact heat exchanger whose alternating fluid passages can be separated. It was developed to facilitate easy coupling of multiple satellite fluid systems to a central one. A novel circulation pattern in the coupler provides a high effectiveness for heat exchange while preserving both separation and independent circulation of two different fluids. Finally, in order to provide accurate servo-feedback control and flow regulation for a circulating PCM slurry system, an inexpensive slurry flowmeter was designed and developed for use at the typical low-flowrates in such systems. The electrical output for the device is linear for flows over a wide range and the device can operate with opaque slurries of varying solids concentrations and without introducing additional thermal loads.

A number of patents have been filed regarding these new technologies. Commercial applications for devices and systems include both passive and active electrical and mechanical systems for enhanced thermal management (heating, cooling, or storage). Examples of such systems might be high-powered radar tubes or electronic components, fluids and lubricants with enhanced thermal capacitance, powdered and molded PCM heat sinks for electronics, improved circulating coolants, quick disconnect fluids couplers or mating compact heat exchangers, slurry flowmeters, and flexible heat shields or thermal barriers with enhanced transient thermal capacitance.

This research was performed by Dr. David P. Colvin of Triangle Research and Development Corporation, (919) 467-2878. The contract was administered by William L. Haskin, Wright Research Development Center, Flight Dynamics Lab at Wright-Patterson AFB; (513) 255-4853. ■

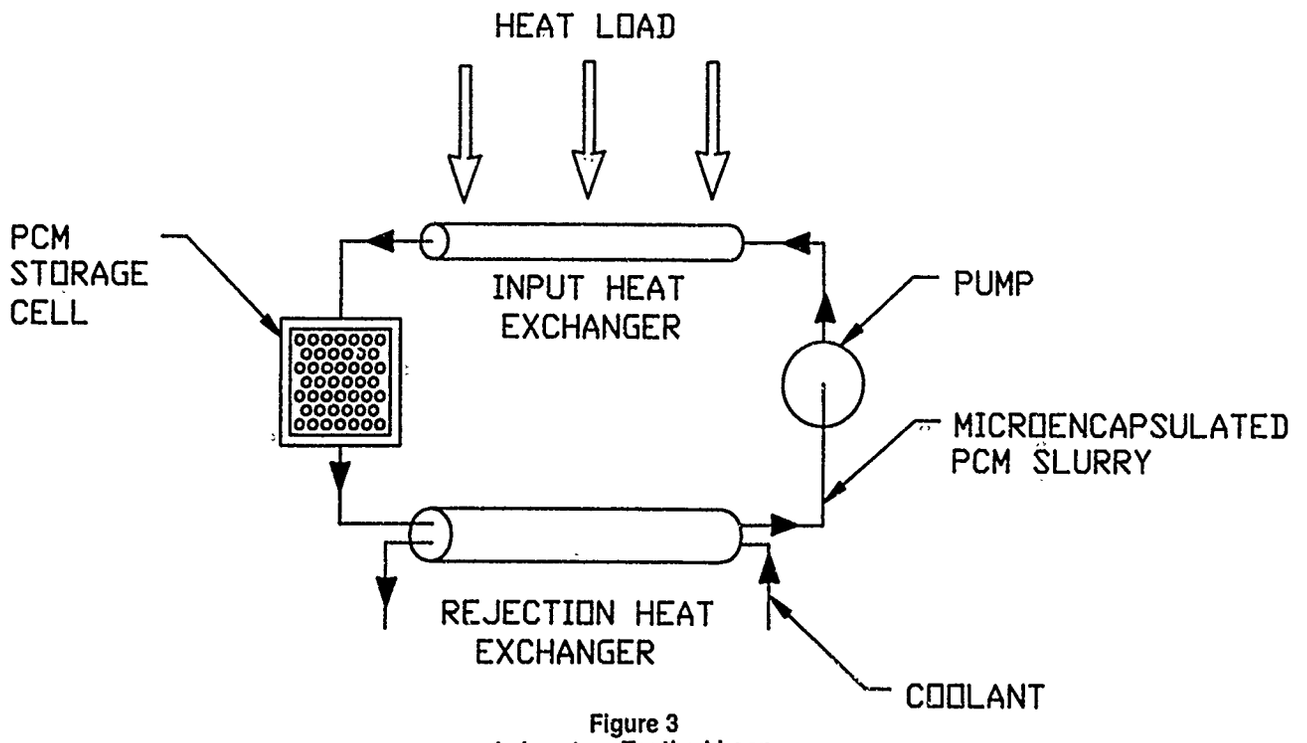


Figure 3
Laboratory Testbed Loop

Hybrid Fiber Carbon-Carbon Composites for Improved Compatibility with Oxidation Resistant Coatings

Carbon-carbon composites are finding ever increasing opportunities for use as high temperature, lightweight, structural components in the aerospace and defense fields. No known material can rival the high temperature strength of carbon-carbon composites. Significant opportunities exist for their use in severe environments, such as aircraft engines and high velocity airframe structures. Unfortunately, carbon-carbon is susceptible to rapid degradation in these types of environments unless it is protected from exposure to oxygen. Current protection systems rely on thin layers of oxidation resistant coatings which are applied to the outer surfaces of the carbon-carbon. Since these ceramic coatings react to rapid heating and cooling differently than does carbon-carbon, such coatings tend to crack and fall off quite readily, exposing the carbon-carbon composite. The lack of a reliable coating system has prohibited the widespread use of carbon-carbon in oxidizing environments. This in turn, has delayed the realization of such potential benefits as increasing engine operating temperatures to dramatically improve efficiencies.

One approach to reducing this coating failure problem was explored and demonstrated in this project. A series of hybrid composites were developed, which incorporated ceramic fibers into the surface layers of the carbon-carbon composites. The goal of this approach was to modify the surface thermal expansion characteristics of the carbon carbon composites to more closely match the behavior of the ceramic coatings, without sacrificing the high temperature strength properties unique to carbon-carbon.

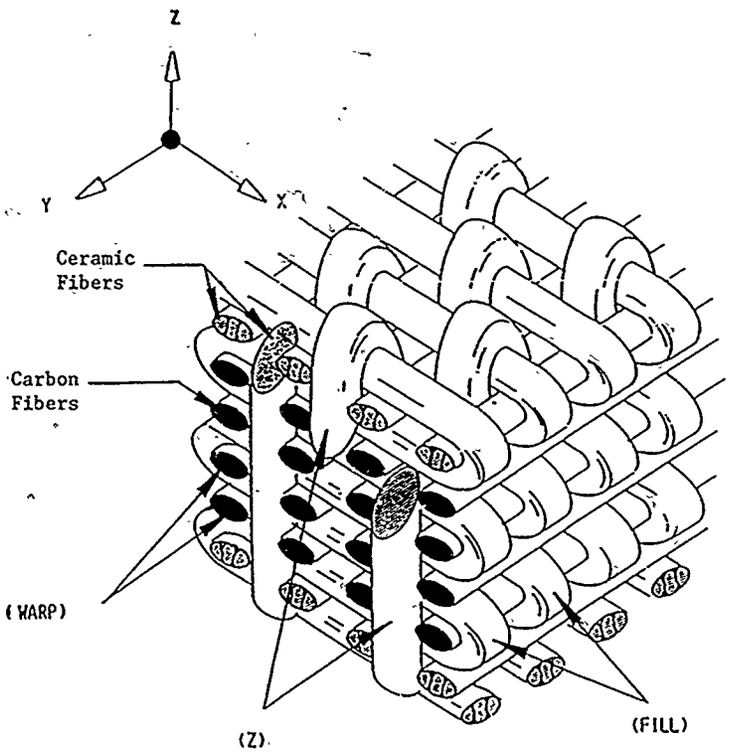


Figure 1
Three-Dimensional Weave Schematic

This was accomplished by weaving layer(s) of ceramic fibers into three-dimensional carbon fiber preforms as shown schematically in figure 1. Silicon carbide and alumina-boria-silica fibers were woven in combination with intermediate modulus and high modulus carbon fibers to explore the effectiveness of various yarn combinations and weave configurations. After repeated processing cycles to deposit the carbon matrix material, the resulting composites were tested to determine the effects of the ceramic fibers on the composite behavior during rapid heat up and cool down. The spectrum of typical behaviors observed is shown in figure 2. The most successful ceramic carbon combinations, or hybrids, showed thermal expansion curves nearly identical to those of the ceramic coating material. A typical curve for an unmodified baseline carbon carbon is included for comparison.

The successful incorporation of ceramic fibers into the carbon-carbon composites without

significant degradation of either type of fiber was a milestone in itself. These hybrid fiber composites were then coated with a silicon carbide ceramic coating and tested for coating integrity and effectiveness in ovens set at high temperatures representative of proposed application environments. A typical plot of these screening tests is shown in figure 3. Again a wide spectrum of performance was obtained. Those hybrids which had shown the best thermal compatibility with the coatings (figure 2) demonstrated the best resistance to oxidation when coated.

The demonstrated improvement in the effective performance of state-of-the-art coatings through this composite surface modification approach opened the doors for many other applications of this hybridization technology—both in the coated carbon-carbon area and in other composites as well. Thermal expansion behavior has been added to the list of composite material properties which can be tailored to a set of performance requirements through the appropriate selection of reinforcing fibers. For carbon-carbon, this technology is limited currently by the temperature capabilities of available ceramic fibers. As new fibers are developed with improved stability at higher temperatures, this technology should expand the list of useful coatings for carbon-carbon. The continued development of these hybrid composites also offers the potential to reduce the current dependence upon intermediate sealant and transition layers under ceramic coatings. As a result, the complexity and cost of these protective coating systems can be reduced.

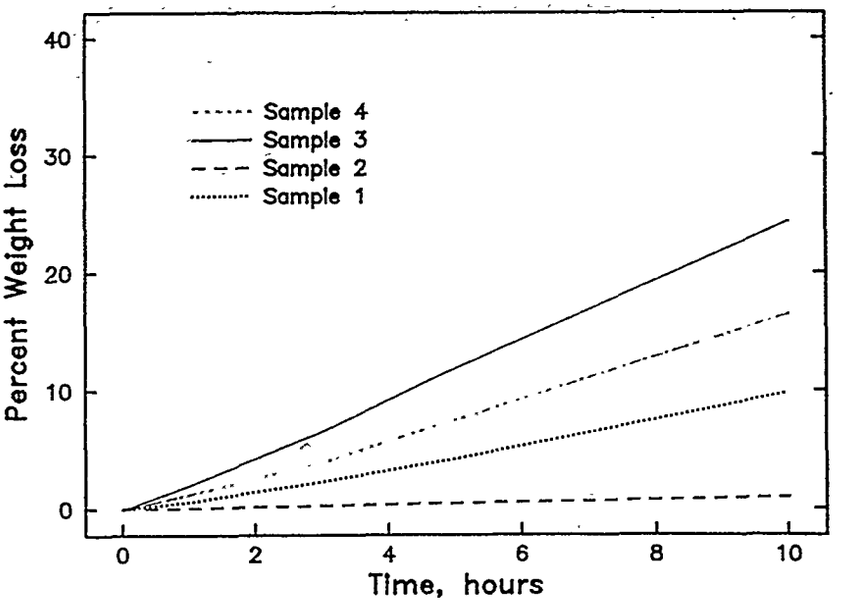


Figure 3
Silicon Carbide Coated Samples at 871°C

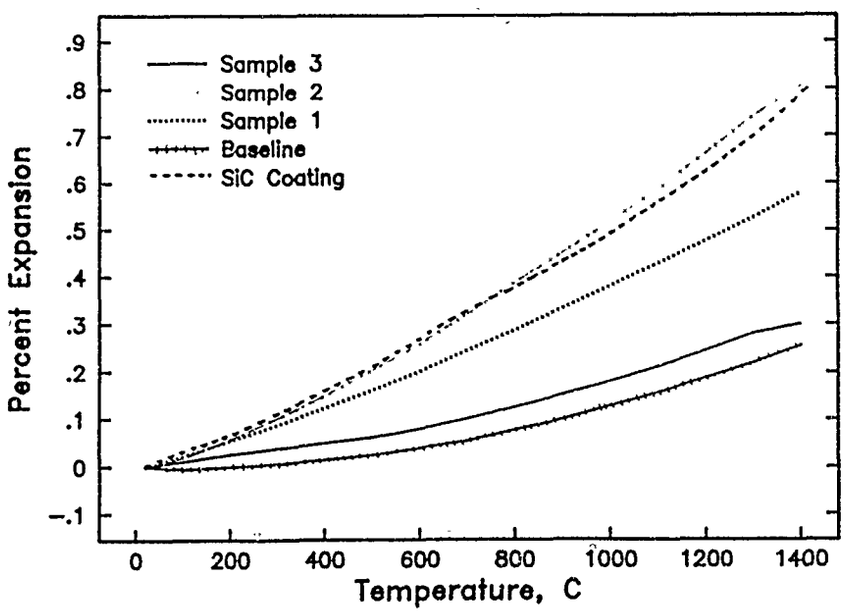


Figure 2
Pitch Matrix Hybrids: Thermal Expansion vs. Temperature

This demonstrated hybrid fiber approach also offers considerable potential for use in combination with other existing efforts focusing on improving inherent oxidation resistant capabilities. When used in conjunction with state-of-the-art coating techniques, this technology will bring the Air Force one step closer to achieving a practical lifetime for components made from carbon-carbon, thereby expanding the range of applications for this unique and vital material.

This research was performed by M. B. Keller of Fiber Materials, Inc.; (207) 282-5911. The contract was administered by Lt. Dennis Maloney, Wright Research Development Center/MLBC at Wright-Patterson AFB; (513) 255-3670. ■

Emergency Breathing Apparatus (EBA)

There is no foolproof protection possible in emergency situations where highly toxic volatile chemicals are involved. The best that can be accomplished is to minimize the delay between recognition of the emergency and donning of available protective gear. The best way to minimize this delay is to require that workers carry the protective gear at all times. Unfortunately, existing respiratory protection devices are too large to be carried without interfering with work, and are therefore stored at strategic locations. Experience in actual hazardous situations resulting in the death or injury of workers has demonstrated that when a life-threatening emergency occurs, the majority of workers tend to panic and leave the hazard area without first making an effort to locate and don the protective device.

Since most personnel working in hazardous environments are already required to wear hard hats, a prototype self contained breathing apparatus (SCBA) incorporated into a hard hat with an attached belt pack solid-chemical oxygen source was designed and tested. If an emergency occurs, the worker need only start the oxygen supply, pull down the transparent hood packed within the hard hat brim, and exit the hazardous environment. Figure 1 shows a prototype hard hat containing SCBA.

In addition to the transparent hood permanently stored within a brim compartment, a venturi aspirator and a carbon dioxide scrubber chamber are molded into the hat. The aspirator is powered by the belt pack oxygen generator and draws the expired air through the chemical-filled scrubber chamber to remove metabolically produced carbon dioxide. Figure 2 schematically illustrates the SCBA.

The use of the aspirator system allowed the user's lungs to function without additional pressure loads. It also reduced the stringent requirements for leak-free sealing, provided an audible indication of the approach of oxygen depletion, and facilitated optimization of the scrubber chamber for high scrubbing efficiency.

An aspirator design study investigated orifice size and position, throat diameter, and length. In addition, the study explored outlet nozzle taper and length to find the optimum aspirator dimensions which create the greatest possible induced flow through the SCBA system. Aspirator design parameters, which provide a high induced flow rate at a pressure well within the oxygen generator safety limits, were then chosen. The present aspirator system produces a free recirculation flow rate through the empty flow channels - scrubber compartment of approximately 140 liters per minute (lpm) using an 8 lpm oxygen supply operating at 24 psi. The addition of the scrubber chemical packing to the scrubber compartment increases flow resistance and results in a decrease in the recirculation rate

Figure 1
Hard Hat Prototype with Self-Contained Breathing Apparatus

through the scrubber bed to 70 lpm. At 70 lpm the hood is flushed approximately 15 times per minute. Alkali and alkaline earth metal hydroxide scrubbers were found to be most efficient in this situation. Metal hydroxides reacted with carbon dioxide to produce carbonates and bicarbonates with the liberation of water as indicated by the following generalized reactions for the alkali metal hydroxides:

$2MOH + CO_3 \rightarrow M_2CO_3 + H_2O$

$MOH + CO_2 \rightarrow MHCO_3$

Table 1 summarizes the major properties of the most commonly used scrubbers.

Lithium hydroxide, the most efficient and most widely used scrubber chemical for SCBA devices, was found to produce unacceptably high temperatures for use in this application. As a result, an extensive study to find or modify existing scrubbers to reduce the reaction temperature was undertaken. The major problems found with non-LiOH scrubbers was the high level of moisture produced by the scrubber, initial water content of the scrubber, and moderately-high temperatures produced during the reaction. A commercial sodalime (calcium hydroxide plus activators) manufactured in England was selected as the best compromise between efficiency of carbon dioxide removal, reaction temperature, and water production characteristics.

Preliminary laboratory tests using a NIOSH Man Test #4 simulation for a 10 minute service have been uniformly satisfactory. The tests used treadmill equivalencies to simulate the different sequential activities in the NIOSH protocol. The overall performance was within published respiratory function safety limits.

An emergency self contained breathing apparatus has been incorporated into a protective hard hat in order to reduce the user response time between hazard recognition and provision of respiratory protection. Its purpose is to increase survival odds if a worker is suddenly exposed to toxic chemical fumes without encumbering the worker by additional bulky protective equipment.

This research was performed by Kenneth Abel of The Abel Company; (703) 626-3036. The contract was administered by Dr. Raymond Bernberg, Air Force Space Technology Center at Los Angeles AFB; (213) 336-4515. ■

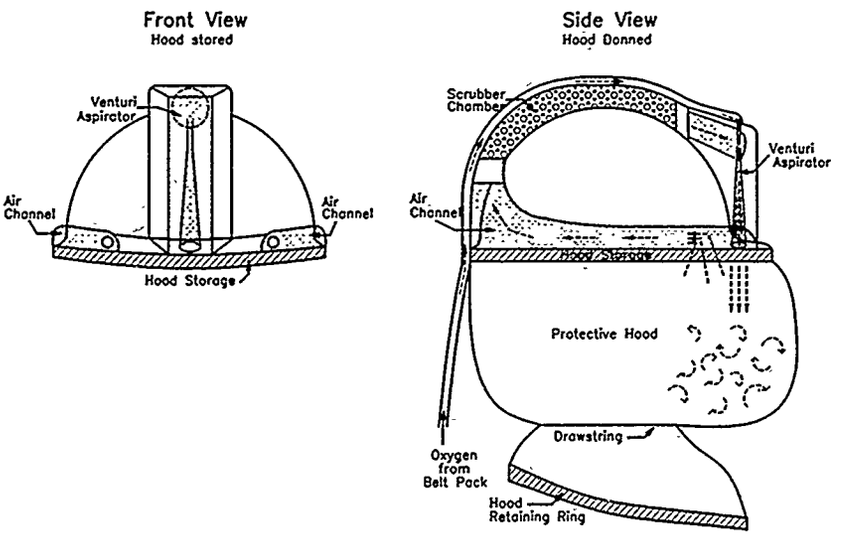


Figure 2
Cross-Section of Self-Contained Breathing Apparatus

Properties of Major CO2 Scrubbers

Compound	Formula Weight	Capacity (gCO_2/g)	Reaction Heat (cal/gCO_2)
LiOH	23.9	0.919	512
NaOH	40.0	0.550	694
KOH	56.1	0.392	814
$CA(OH)_2$	74.1	0.594	376
$Mg(OH)_2$	58.3	0.754	106
Soda Lime	46.8 (typ)	0.488	*
Baralyme	87.5 (typ)	0.503	*

Table 1
Major CO_2 Scrubber Properties

Development and Structural Application of Carbon-Carbon Joining Technology

High temperature carbon to carbon (C-C) joining technology is needed for structures and components of new hypersonic missiles, reusable reentry vehicles, aircraft brakes, and rocket and jet engine components. Joints are needed to fabricate structures and attach high temperature components to supporting structures. Often these joints will have high service temperatures (2500°-3000°F), similar to the C-C service temperature. Previous joining work on C-C has produced either epoxy joints for service below 500°F or intermediate temperature joints made by brazing with active filler metals (silver base alloys). These alloys have use-temperatures of 1000°F or less and low mechanical properties at elevated temperatures.

Elevated temperature C-C joints required new joining methods. Development of a series of interlayer materials and processes appear to satisfy these requirements. Techniques for C-C surface preparation were also explored. These ranged from chemical cleaning to ion techniques, such as ion implantation and ion mixing. Results from these methods were examined by metallographic, optical, and scanning electron microscope (SEM) techniques.

A vacuum furnace with a 15 kW, 10 kHz induction heating unit was used to heat these specimens for joining as shown in figure 1. The vacuum was drawn inside a quartz tube, which had been evacuated through a cold trap, diffusion pump, and a roughing pump to below 1×10^{-4} torr. Induction heating was accomplished by susceptoring the tool used to hold the specimens together during brazing/diffusion welding.

Evaluation was done by several sequential techniques including stereomicroscope examination at 30X to evaluate the joint edges for filling, gaps, external flow of interlayer material, and adherence to the C-C surfaces. Figure 2 is a representative photograph, showing the relative amounts of external flow for several candidate interlayer materials. At 5.2X

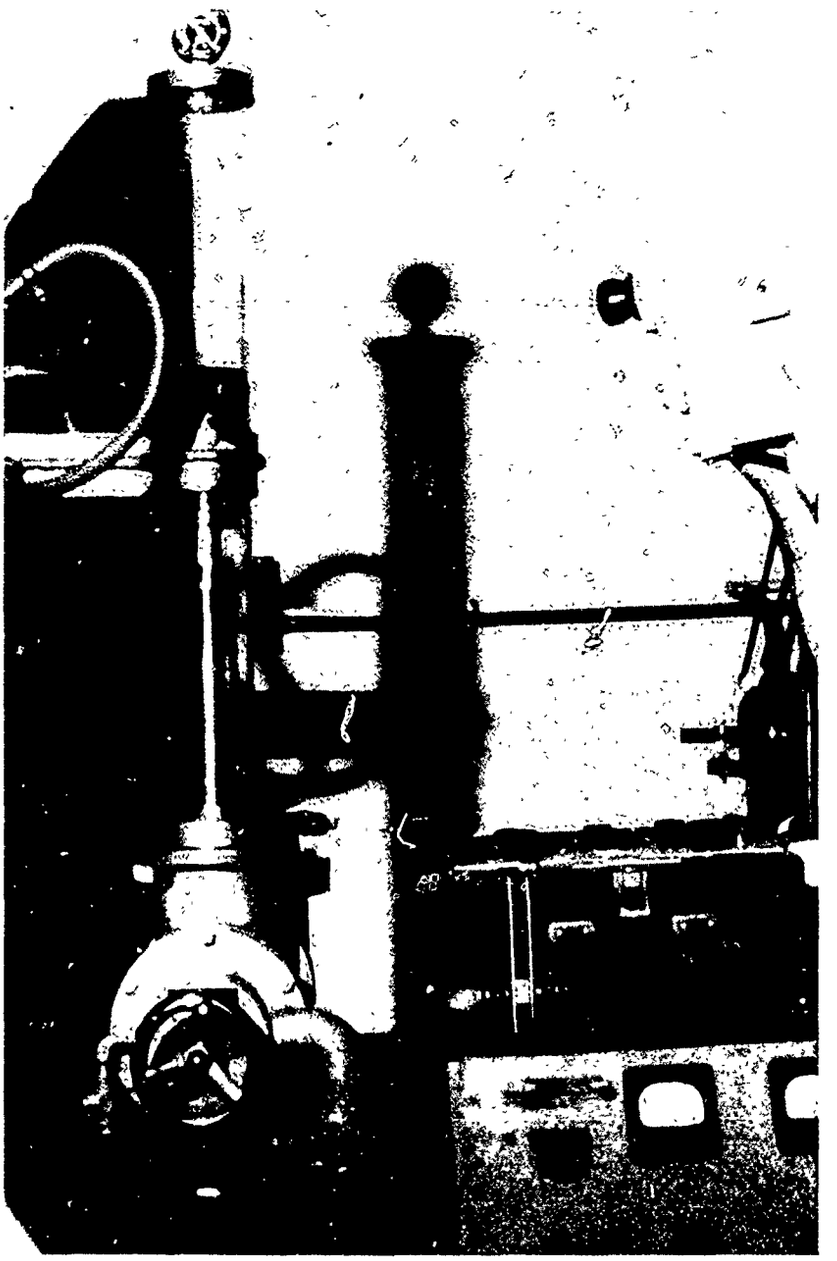


Figure 1
Induction Vacuum Furnace for Joining Carbon-Carbon Composites

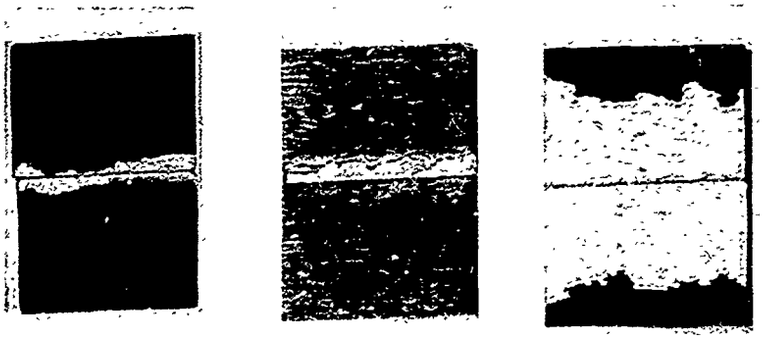


Figure 2
Sample Materials After Joining

magnification, the sample at the far right demonstrates characteristic surface spreading outside the joint, therefore, a good coating candidate.

Specimens were bent by hand with the joint placed in bending. Any specimens which failed were not evaluated further. Optical metallography was performed on promising specimens by sectioning in a plane perpendicular to the joint interface. Sections were mounted, polished, and in some cases, etched before examination at magnifications to 1000X. Microhardness readings were taken in interlayer materials on the polished sections.

Scanning electron microscopy combined with energy dispersive x-ray was used to examine the metallographic sections. Figures 3A & B show a promising joint with both optical and scanning electron microscopic methods. Photo 3A represents the interlayer at center viewed by an optical microscope at 100X; 3B is an enlargement of the interlayer, with SEM showing penetration of joining material into substrate cracks.

With most interlayers and surface preparations evaluated, excellent bonding to the C-C material surfaces was obtained. This was confirmed through examination both by optical microscopy and by SEM at magnifications to 5000X. Good wetting of the faying surfaces was apparent; as well as, wetting and filling of cracks in the C-C material for some of the interlayers evaluated. All the interlayers used have the potential of forming high temperature, high strength compounds at the interface. Properties such as room temperature, intermediate temperature and high temperature tensile, shear, and fatigue strength are being evaluated for small samples. Prototypic component testing is also in the works. Compatibility of these interlayer materials with typical coating materials and procedures will also be determined.

This research was performed by Kenneth H. Holko of Materials Innovation Laboratories; (619) 586-7929. The contract was administered by Harold Croop. . . Wright Research Development Center, FIBCB at Wright-Patterson AFB; (513) 255-2582. ■

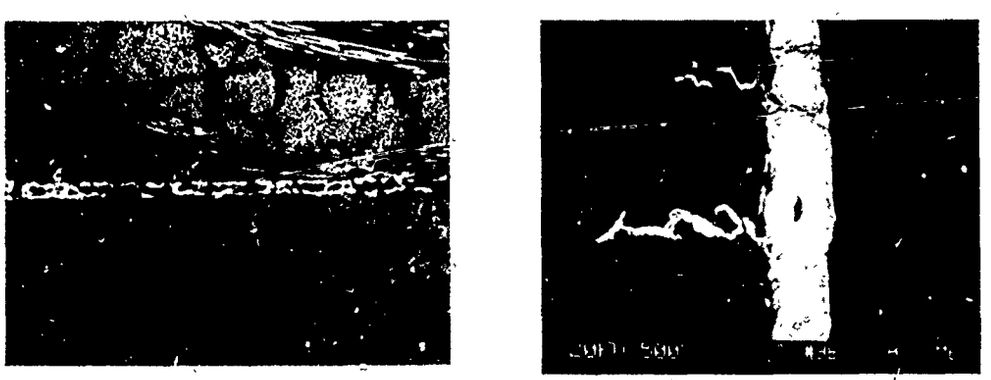


Figure 3
Carbon-Carbon Composite Joints Via Optical and Scanning Electron Microscopics

Results of Phase II Contracts

This section contains abstracts of Phase II contracts, summarizing the nature and scope of the project and the work accomplished. These abstracts are organized by technical area. An index provided at the back of this publication lists contractors alphabetically by company name and contracts by research title(s). In the event that additional information is required, the name, address, and phone number of the responsible contractor is included at the end of each abstract.

The views and opinions expressed in the Abstract Section are those of the Small Business Innovation Research contractors and do not imply Air Force endorsement, factual accuracy, or opinion.

■ AIR VEHICLES

Optimizing Manufacturing Tolerances in Rolling Bearings for Critical DoD Applications

Rolling bearings are very often regarded as the most critical mechanical components of a rotating machinery system. The behavior of these bearings generally controls the performance and operating life of the entire mechanical system. In critical applications the manufacturing technology is often driven to its limit in producing "best possible" bearings. Such an approach results in very high manufacturing costs. Also, in absence of a clear understanding of the significance of various manufacturing tolerances, some of the critical tolerances are sometimes overlooked. With the use of highly sophisticated computer modeling techniques, this investigation presents an innovative approach to modeling the influence of manufacturing tolerances on rolling bearings and thereby determining a realistic tolerance specification for prescribed bearing performance.

The bearing dynamics computer code, ADORE, is used to parametrically model bearing performance as a function of the various geometric imperfections, or manufacturing tolerances. Both oil and solid lubricated bearings, typical of high-speed turbine engine applications, are considered. The imperfections investigated include ball size variation, ball unbalance, preferred axis of inertial, race out of roundness, variations in race groove curvature, and cage unbalance in ball bearings. In cylindrical roller bearings, the bearing performance is modeled as a function of race out of roundness, taper in the race and roller surfaces, centrality of flat land on the rollers, roller size variation, roller unbalance and tilt of the inertial axis, and cage unbalance. With prescribed defects in race geometry, the imperfections on the rolling elements are statistically distributed and bearing performance is correlated to the rms deviations of the imperfections. The bearing performance is evaluated in terms of life, power loss, cage interactions and stability, roller skid and skew instability, guide flange interaction and roller end wear. From the general trend of variation of these performance parameters, practical guidance for obtaining the permissible limits on the various geometric imperfections is obtained and a general procedure for tolerance optimization for a given bearing under prescribed performance requirement is outlined.

COMPANY: Pradeep K. Gupta, Inc.
PHONE: (518) 383-1167
CONTACT: Dr. Pradeep K. Gupta

Low-Cost Synthesis of Poly (Benzobisthiazole) with Enhanced Mechanical Properties

The purpose of the Phase II program is to demonstrate improved performance in engineering structures based on the exceptional mechanical, thermal, electrical, chemical and optical properties of PBT ordered polymers. Phase I demonstrated the feasibility of preparing Cis PBT in high yield, via a rapid, low cost route. The results of this study also led to novel concepts that are being used to solve two major problems involving ordered polymers, namely, poor compressive strength and low interlaminar shear strength. The Phase II effort is addressing the following: polymerization of Cis PBT to high molecular weight in larger quantities; synthesis of PBT containing articulated monomer linkages; extrusion of fibers and films from Cis, Trans and Articulated PBT and demonstration of improved cost and performance over other materials by mechanical characterization.

Low cost PBT polymers with improved mechanical properties will outperform other materials such as metals and ceramics because of their exceptional combination of properties such as light weight, high strength to stiffness ratio, low radar signature, nonlinear optical behavior, low controllable CTE, high thermal stability and resistance to laser and ionizing radiation. In spacecraft structures, improved PBT polymers will exhibit high damping, low CTE and ballistic impact resistance. Advanced aircraft structures will benefit from the improved compressive strength and high interlaminar shear strength of composites made from these materials.

COMPANY: Foster-Miller, Inc.
PHONE: (617) 890-3200
CONTACT: Dr. Robert Kovar

Fluid Filled Aircraft Transparencies

Future Air Force aircraft are expected to encounter operational environments and combat threats that will require advances in the design and performance of their transparent windshields, canopies and windows. These environments and threats include sustained high speed flight, high altitudes, and effects from laser weapons and nuclear blast. The Air Force Forecast II initiative recognized these problems and identified the need for advancements in related key technology areas such as those associated with Cooling of Hot Structures.

Objective of this SBIR program was to design, fabricate and test prototype aircraft transparency system models that demonstrate the required protection from aerodynamic heating, infrared (IR) radiation heating, incandescent flash, and surface abrasion.

Program approach includes design and construction of a thermoelectric cooled circulating fluid system that contains IR absorbing dyes, utilizes a heat reflecting gold layer, and a command controlled dye reservoir and valve system to achieve rapid opacification. A photochromic electrophoretic system is incorporated into the structure to achieve an ultrafast flash protection. This system uses photochromic dyes and a bilayer of conductive semitransparent film, one of which is used to store the dye in the transparent mode and one for the opaque mode. Several outer hard coating materials will be tested. Prototype models are tested for transparency, thermal efficiency, optical properties, and rates for transparency and darkening. These models provide the data essential for design and fabrication of production, fluid filled transparency systems of advanced Air Force aircraft.

Commercial applications include inproved flash protection shields and masks, cooling or thermal blankets for protecting aircraft cockpits against extreme temperature excursions while parked on runways, and conductive transparent films on plastics or glass.

COMPANY: Sputtertex Corp.
PHONE: (214) 869-3456
CONTACT: Boyd L. Justice

Improved Pins and Bushings for Aircraft Landing Gear

An alternative is being sought for traditional pins and bushings in aircraft articulated landing gear. Current bushings, which are softer than pin coating materials, must be replaced if worn or if corrosion is suspected at the interface between the bushing and the landing gear lug. The process of refurbishment is costly, time consuming, and can be accomplished only at special remote maintenance facilities.

This work is directed at finding hard bushing and soft pin surface coatings to transfer wear to the more easily replaced pin. The search concentrates on surface treatments rather than solid materials because the long term goal of the program is to eliminate bushings entirely. If hard, tough surface coatings can be placed directly on the landing gear lugs, the troublesome bimetallic bushing lug interface can be eliminated. However, the intermediate step will be to coat bushings made of strut lug material to reduce corrosion problems caused by dissimilar metals.

Several combinations of pin and bushing coating materials were demonstrated successfully during the Phase I effort, and are being tested further during Phase II. Pin coatings incorporating silver worked best for high lubricity and galling resistance. Tungsten carbide cobalt and electroless nickel appear to be promising candidates for bushing lug coatings.

When successful, this program will greatly reduce the frequency of landing gear overhaul by eliminating the need to inspect for interface corrosion, reducing the overall wear of the pin bushing combination, and increasing field servicing capability. The benefit is enhanced front line readiness and reduced maintenance and repair costs.

COMPANY: Foster- Miller, Inc.
PHONE: (617) 890-3200
CONTACT: Daniel Fischbach

■ AIR VEHICLES

Development of Non-Conventional Control Methods for High Angle of Attack Flight Using Vortex Manipulation

Future air combat arenas will require fighter aircraft performance that exceeds the capabilities of present-day aircraft. One of the key technologies to advance the overall capability of the airplane is aerodynamic control. The flight envelope of current aircraft has been limited at least in part by controlability problems at high angles of attack, where strong vortex flows on the forebody and wing leading-edge extensions (LEX) can produce large uncontrollable yawing moments, roll departure, and in some cases, a pitch-up or deep-stall condition.

The objective of this study is to explore the use of non-conventional methods of aerodynamic control utilizing these vortex flow phenomena to advantage. Studies have shown that controlled manipulation of forebody and LEX vortices on fighter-type aircraft configurations can be extremely effective in providing high angle of attack control and enhancing the potential for increased maneuverability. Research experiments on a series of generic fighter configurations have investigated several methods to manipulate the forebody and LEX vortex flows. Small geometric surfaces (mechanically-driven or fixed non-conventional surfaces, such as strakes, fences or spoilers) and pneumatic techniques such as surface blowing have all been found to create significant control forces.

The study has concentrated on selecting the most effective methods through extensive flow visualization tests using water tunnel facilities and with force and moment tests in wind tunnel facilities. Analysis of the wind tunnel data leads to a free-flight wind tunnel test to demonstrate the utility of the most promising vortex control methods. A free-flight generic fighter model is under construction and will be instrumented and flown in the NASA Langley full-scale wind tunnel early in 1989. A successful demonstration of vortex control could lead to continued research on a full-scale airplane configuration and eventual flight test.

COMPANY: Eidetics International, Inc.
PHONE: (213) 373-9316
CONTACT: Gerald N. Malcom

Development and Structural Application of Carbon-Carbon Joining Technology

Carbon-Carbon composites (C-C composites) are elevated temperature structural materials consisting of high strength carbon fibers within a binder of carbonized material. Their thermal and mechanical properties have found uses in aircraft brakes, rocket engines, and the control surfaces of aerospace vehicles such as reusable reentry craft (the space shuttle), and hypersonic craft such as various missiles and the National Aerospace Plane (NASP). Commercial uses are being found, such as: medical prostheses which take advantage of the compatibility of C-C materials with body; and automotive clutches and brakes for higher performance cars which take advantage of strength, thermal stamina and heat spreading properties.

Materials Innovation Laboratories (MIL) has developed joining materials and methods for C-C composites, using a family of interlayer materials which are expected to provide strengths equal to the substrate to 3,000 degrees F. The efficient joining of any type of composite to other composites, ceramics or metals in always a challenge. This is particularly true for C-C materials at their 2,000 to 3,000 degrees F typical use temperatures. The only alternative to joining is the use of fasteners such as screws made of refractory materials which are useful for removable inspection covers but are relatively inefficient compared to joining in regards to the often crucial parameters of strengths and weights.

Under sponsorship of the Air Force Flight Dynamics Laboratory, mechanical properties testing in shear and tension of joined specimens to 3,000 degrees F is under way at MIL. Results are presently incomplete, but promising. Joining C-C composites to other materials for various space applications is also being performed.

COMPANY: Materials Innovation Laboratories
PHONE: (619) 586-7929
CONTACT: Kenneth H. Holko

Combined Holographic-Infrared Inspection of New Materials

Designers are turning more often to lightweight, strong organic matrix composite materials for aircraft, missile, automotive, ship and other construction applications as demands increase for fuel efficient, high payload vehicles and lightweight structures. These composite materials must be inspected nondestructively during manufacture and in service to detect defects and damage that will degrade performance or lead to failure. Traditional nondestructive inspections for this new class of materials have relied on methods previously used to inspect metal structures. Typically, these involve ultrasonic and x-radiographic inspection. Both of these methods are difficult to use on large components, particularly in a field environment. Holographic interferometry and infrared imaging are newer inspection methods, both of which have been found useful for the inspection of composite materials.

In this Air Force sponsored program, a combined holographic infrared inspection method is being developed. The combined method, employing thermal excitation of the inspection part, offers improved inspection capability while retaining the advantages of each method.

Advantages include large area coverage, good sensitivity, response within seconds and good interpretation capability as provided by the images produced by each method. The combined inspection approach is leading to a new inspection instrument for the detection of delaminations, voids, foreign material and other anomalies in composite structures. Infrared methods provide good sensitivity even for stiff skin composites that present problems for holography, holographic methods present good response for metal structures that may lead to spreading of the infrared signal. Together, the combined methods present information about defect size, depth and type. The new inspection instrument will be offered commercially.

COMPANY: Industrial Quality, Inc.
PHONE: (301) 948-0332
CONTACT: Harold Berger

Improved Properties of Transparent Plastics by Ion Beam Processes

Crazing of acrylic/polycarbonate materials used as aircraft and cockpit windows is a serious problem in military and civilian planes. The aircraft windows are also damaged by abrasive wear, erosive wear and are subjected to harsh conditions such as acid rain, rain erosion, ozone, deicing fluids, and cleaning agents. A treatment that would provide the surface of acrylic and polycarbonate with corrosion and wear resistance is highly desirable and very much in demand.

The proposed ion beam processes have succeeded in resolving the detrimental delamination problems suffered by conventional surface deposition processes on transparent plastics. They also significantly improved the mechanical properties and chemical resistances of polycarbonate and acrylic materials. The ion beam processes were shown to be versatile and reproducible.

The improved properties of transparent plastics by ion beam treatment is expected to extend the service lifetime of aircraft window and significantly reduce operational cost of aircraft by the Air Force. The added benefits provided by this technology, such as scratch resistance and enhanced conductivity, offers broad potential applications in the areas of automotive sunroofs and headlight covers, electrostatic discharge plastic sheets and hard floorings for semiconductor manufacturers, face masks for the military, and new generation of plastic bearings. The technology should be equally applicable to non transparent plastics which offers tremendous potential for research, development, and commercialization.

COMPANY: Spire Corporation
PHONE: (617) 275-6000
CONTACT: Dr. Piran Sioshansi

■ MATERIALS

Ordered Polymer Films for Multilayer Printed Circuit Boards

The requirements for advanced electronics have exceeded the limits of circuit board materials for weight, interconnection density, and computing speed. Ordered polymer films made from liquid crystalline polymers called PBZ's can provide thin dimensionally stable substrates with very low dielectric constant for use in complex multilayer circuitry.

This program has succeeded in making thin (0.001 in.) film substrates with thermal expansion matched to silicon or leadless ceramic chip carriers (3 to 7 ppm/#C) and low dielectric constant (e_r = 2.8). Copper circuit layers were bonded and signal paths were etched, and multiple layers were stacked to form several signal, power and ground planes. We estimate that this will result in interconnection over 1000 in./in.^{2} and more than 10 percent board area in active silicon.

PBZ ordered polymer films should eventually lead to circuit densities five to ten times those now possible. Advanced computer systems for defense, industrial and consumer applications are dependent on very high speed and large scale integrated circuits. Designs which will use these materials include multichip modules, chip-on-board and flexible circuitry.

COMPANY: Foster-Miller, Inc.
PHONE: (617) 890-3200
CONTACT: Dr. Robert Kovar

Translaminar Reinforcement of Organic Matrix Composites

Transverse reinforcement has been used to increase the delamination strength composites. Organic matrix composites have been reinforced by stitching through the uncured molding. Unfortunately, stitching damages the main fibers and requires handling of the uncured layup outside the tool.

A method has been developed for inserting short spikes of fiber into the uncured material without removal from the tool The fiber spike is inserted with ultrasonic assistance. A light coating of binder rigidizes the spike during insertion. The binder dissolves during cure to leave the transverse fibers completely and individually bound into the composite matrix.

The translaminar reinforcement dramatically improves the delamination resistance while hardly affecting the in-plane properties of the laminate. Stitching has been shown to reduce in-plane strength of a laminate by 20 percent; an equivalent laminate with translaminar reinforcement showed a reduction of in-plane strength of only 5 percent while the delamination resistance was increased fourfold.

Delamination is the mode of failure in composites when they are impacted. The Air Force needs delamination resistance in its composite aircraft. A military aircraft has to withstand impacts as small as a stone being thrown up from the runway to as large as an anti aircraft round. The translaminar reinforcement method is particularly aimed at controlling delamination during ballistic impact on a composite wing. A "wet" wing containing fuel can be devastated by the shock wave or hydraulic ram effect of a ballistic hit. The reinforcement of wing skins and joints will increase the survivability of Air Force aircraft.

The potential benefits of this method extend beyond military aircraft. The technique could be applied to commercial aircraft to use more of the potential strength of composites in lighter structures. Other forms of composites such as carbon-carbon and metal matrix require transverse reinforcement which could be applied to the preforms by the method developed in this contract.

COMPANY: Foster-Miller, Inc.
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CONTACT: J. Boyce

The Bioextraction of Gallium Ore

Gallium has become an important strategic metal. The U.S. demand for gallium is expected to increase at an average annual rate of approximately 7% through 1990 with the development of new electronic, medical and composite materials. New research and development continues on the properties, fabrication techniques and uses of gallium compounds.

The present difficulty concerns the fact that U.S. gallium occurs in very small concentrations in many ores which are mainly sub-economic deposits. The gallium is therefore only partially recovered with current technology, allowing imports to provide most of the supply needed to meet the domestic gallium requirement. Bioleach recovery is remarkably well suited to processing the small gallium concentrations which occur in manufacture byproducts and very dilute metal tailings. Bacterial leaching is a well established process for solubilizing metals and separating these metals from their metal matrices. This approach yields low operating costs and the mitigation of air and water pollution, usually associated with conventional recovery methods.

Technical Research Associates, in this Phase II research and development study, is successfully optimizing and scaling gallium bioextraction with domestic ore supplied by the Apex St. George Mine and five bauxite ores supplied by a private aluminum company.

It is expected that the United States will need the accessibility gallium bioleaching affords to keep domestic stockpiles in good supply, to keep up with projected domestic demand and to successfully compete with improved international markets. There is, therefore, a distinct need for this efficient, domestic, cost effective method of gallium recovery.

COMPANY: Technical Research Associates
PHONE: (801) 582-8080
CONTACT: Gail Bowers-Irons

Use of Expanding Manpower Compositions for Aircraft Coatings

Modern aircraft require organic coatings to protect aluminum structures and polycarbonate transparencies from the erosive and corrosive effects of the environment. Major deficiencies of coatings now in use by the Air Force are. (a) excessive solvent emission when they are applied, (b) the need for incorporating certain toxic additives such as chromium in the aluminum coatings in order to control corrosion, and (c) poor adhesion on polycarbonate transparencies when optical clarity and abrasion resistance is required. This project uses a new concept in polymer coating chemistry, that is, the use of expanding monomers in UV curable coatings. These coatings have. (a) low (<10% b.w.) total solvent emissions, (b) survive over 2000 hours in the salt spray ASTM B 117 procedure on clad aluminum without the use of chromate additives, (c) are optically clear, and (d) have ASTM D 3359 adhesion on either polycarbonate or aluminum of 5A (highest rating). This rating is unchanged after 4 days in water @ 500C and after 3 hours in water @ 100C with no effect on optical clarity.

The development of these coatings resulted in the granting of U.S. Patent #4,738,899 to EPOLIN, Inc. Coatings compositions can now be made at a cost comparable to state of the art Uv coatings because a difficult synthesis of expanding monomer is eliminated. Current efforts are directed at pigmenting the coatings to Air Force colors for use in a dual function on aircraft aluminum—i.e., as a combination base coat and top coat.

The new coatings are candidates for a range of commercial protective applications such as for optical fibers, conformal coatings, eyewear, instrument panels, and for various architectural uses.

COMPANY: Epolin, Inc.
PHONE: (201) 684-3152
CONTACT: Dr. Murray S. Cohen

■ MATERIALS

Application of Ordered Polymers

The goal of this Phase II SBIR program was to achieve increased performance in spacecraft and impact-resistant structures by the application of ordered polymers. Our accomplishments during the program show that this goal was successfully achieved. They include. The design and implementation of a micromechanical model that predicted ordered polymer mechanical properties, development of effective surface treatments for PBT film that improved its adhesive properties, screening of high performance thermoset and thermoplastic resins for use in laminating PBT films, fabrication of PBT film laminates by direct bonding, and resin prepregging techniques, and mechanical testing of PBT film laminates. The compressive and intralaminar strengths of PBT film laminates were greatly improved by resin prepregging, which also linearized and reduced CTE to near-zero values. A PBT film structure/property database was established to facilitate its use in spacecraft and impact-resistant structures.

This Phase II program resulted in follow-on development programs with the U.S. Air Force, U.S. Army, and NASA for lightweight aerospace structures including space station truss tubes, thin walled sandwich structures, and rocket motor cases.

COMPANY: Foster-Miller, Inc.
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CONTACT: Dr. Robert Kovar

Direct Cast Titanium Alloy Strip

Ribbon Technology Corporation demonstrated the feasibility of direct casting titanium alloys by its proprietary melt overflow rapid solidification process. The Phase II project is directed toward casting titanium alloy strip 30cm (12 in) wide and as thin as 0.125 mm (0.0005 in.). The effect of melt overflow process variables on the dimensions of the cast strip are systematically investigated. The first task is to identify different substrate materials for casting titanium alloys. The casting system is physically modeled in air and modifications are made to the caster used during the Phase I project. Twenty four experiments are planned for use with the induction skull furnace operated by Duriron Company in Dayton, Ohio. The direct cast strip is evaluated at the Ohio State University and at the University of Illinois.

Direct cast strip could be used for metal matrix composites for advanced aircraft. The density of titanium alloys is roughly half that of nickel based superalloys now used in the hot stages of gas turbines. One potential commercial application for direct cast titanium strip would be in cathodic protection of bridges.

COMPANY: Ribbon Technology Corporation
PHONE: (614) 864-5444
CONTACT: Thomas Gaspar

Improvement of Compressive Strength in Ordered Polymer Films and Fibers by Sol-Gel Glass Processing

Sol gel glass processing of poly (benzobisthiazole) (PBZT) films increased the compressive strength of PBZT/PEEK film laminates by more than four times, with the potential for further improvement indicated. This was accomplished by infiltrating sol gel glass precursor reagents into microfibrillar regions of PBZT film, forming PBZT/sol gel glass microcomposites that combined the high compressive strength of glass with the exceptional strength and toughness of PBZT ordered polymer. The presence of glass within PBZT/sol gel microcomposite films inhibited the buckling of microfibrils during film compression, greatly increasing the resistance of the films to compressive failure. The use of sol gel glass compositions that fuse at temperatures within thermal stability limits of PBZT (600#C) should further improve PBZT film compressive strength.

We are presently continuing our experiments using sol gel glass formulations that are more compatible with PBT film processing and glass loadings that optimize compressive strength.

COMPANY: Foster-Miller, Inc.
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CONTACT: Dr. Robert Kovar

High Temperature Metal Matrix Composites

The goal of this program was to demonstrate viable high-temperature metal-matrix-composite materials having lower density than conventional super-alloys and possessing equivalent mechanical properties. The composite system of primary interest was titanium carbide (TiC) particulate-reinforced superalloy 718 made by powder metallurgy processing techniques. The process involves hot consolidation of the composite powder blend to 100% density followed by hot-working to improve mechanical properties.

Initial efforts were aimed at defining the fabrication parameters using small 11, 3-inch diameter billets. Having accomplished this, the process was scaled up to 6-inch-diameter billets weighing about 45 pounds each. The powder blends were consolidated to full density by hot isostatic pressing and the billets were hot-extruded to ½-inch x 3-inch rectangular bar. With experience, the extrusion parameters became increasingly well defined. Composites made with 20% and 25% (by volume) TiC reinforcement in Alloy 718 were shown to have considerable promise for high-temperature applications. With appropriate heat treatment of the composites for matrix strengthening, at 1300 degrees fahrenheit the increase in yield strength of the composites compared to unreinforced heat-treated Alloy 718 was 13% for the 20% TiC and 18% for the 25% TiC loadings, respectively. The densities of the two composites are 8% and 10% less than Alloy 718.

In terms of specific yield strength (yield strength/density) at 1300 degrees fahrenheit, the increase of the composites compared to Alloy 718 are 23% and 31% for the two TiC loadings, respectively. Further, the specific yield strength of the composite at 1300 degrees fahrenheit is higher than that of Alloy 718 at 1000 degrees fahrenheit. Additional benefits of the composites compared to Alloy 718 are higher specific modulus of elasticity (specific stiffness) and significantly lower coefficient of thermal expansion. Test results indicate that the TiC/Alloy 718 composites tested in this program have the potential for near term elevated temperature application with substantial weight savings.

The fabrication technology gained from this program is directly applicable to other, more-advanced high-temperature metal-matrix-composite systems.

COMPANY: DWA Composite Specialties, Inc.
PHONE: (818) 998-1504
CONTACT: Edward C. Supan

Chemical Vapor Infiltration Processing for Structural Ceramic Composites

Fiber reinforced silicon base ceramic composites with temperature capability in the 1100 1500 degree C range are promising material candidates for advanced gas turbine engine components. These "toughened" structural ceramics offer the potential for improved reliability as well as the advantages of higher engine operating temperatures, lower weight, greater thrust to weight ratio and reduced dependence on strategic materials.

The purpose of this program was to develop the technology to fabricate ceramic matrix composites by chemical vapor infiltration (CVI) processes on a laboratory scale. The potential advantages of the CVI process are. 1) Low temperature, low pressure processing can avoid fiber degradation or damage, 2) Fiber matrix interface properties can be tailored by varying deposition parameters, and 3) Infiltration of matrix material in a gas phase allows processing of near net shape parts.

Silicon carbide matrix composites reinforced with continuous silicon carbide fibers were produced that exhibited non catastrophic, composite behavior when tested in air at temperatures exceeding 1200 degree C. Reduced manufacturing time and improved mechanical and thermal properties were attained by innovations in processing techniques, fiber-matrix interface coatings and fiber preform architecture.

Prototype ceramic composite engine components fabricated by CVI have been tested and show exceptional promise as lightweight, net shape structures. Advanced fiber reinforced ceramics with complex, near net shape capability have potential for both aerospace and industrial applications. The technology developed in this program will be directly applicable in a Department of Energy program for evaluating high pressure industrial heat exchanger concepts and in a Gas Research Institute program for developing radiant burner tubes for gas furnaces.

COMPANY: Amercom, Inc.
PHONE: (818) 882-4821
CONTACT: Curtis V. Burkland

■ MATERIALS

Non-Destructive Evaluation of Thin-Shelled Structures

A need currently exists within the Air Force for a more effective technique to non-destructively evaluate thin-walled structures such as solid rocket motor components. Current techniques are time-consuming and inefficient. This project involved the design and construction of a pre-prototype laminography X-ray scanner capable of efficiently inspecting thin-walled structures in a fraction of the time required by other inspection methods of similar quality. The laminography scanner operates by taking a series of digital X-ray radiographs at different angles and processing the data to obtain detailed images of specific layers in the object. The images are shown as if a thin-walled cylinder, for example, were unwrapped layer by layer and laid flat.

The scanner can handle objects up to 20 inches in diameter and 22 inches in length. The scanner is complete with all necessary computer hardware and software to perform the scans in a very efficient, user-friendly manner. Output from the scanner is in the form of a digital array of values which are displayed as different colors on a television monitor allowing for informative visualization of the data.

The results of the program demonstrate laminography as a quick, efficient process that gives detailed information of the internal composition of layers within a thin-shelled part. For solid rocket components such as carbon-carbon rocket nozzles, laminography can detect manufacturing flaws which can compromise structural integrity and result in unacceptable, or even catastrophic, degradation of performance. Detection of damage throughout the fabrication of these parts can save millions of dollars in processing costs and better insure the safe operation of such components. Laminography also has the potential for application to a wide variety of non-military inspection needs of thin-shelled structures.

COMPANY: Advanced Research & Applications Corporation
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CONTACT: Dr. James H. Stanley

Crystal Growth of Cadmium Telluride by the Heat Exchanger Method

Cadmium Telluride (CdTe) crystals are required for use as substrates for infrared detectors, modulators in laser radar, and nuclear particle detection. It is also useful for photoconducting, electro optic, charge coupled, photocapacitator and photovoltaic devices. While CdTe is an important crystal, it is very difficult material to grow and industrial growth of completely single crystal material has not been achieved. Approximately 2 inch diameter charges are directionally solidified and the material is "mined" for single crystals. The low thermal conductivity of CdTe makes it difficult to control the solid liquid interface with crystal growth parameters. Attempts to solidify larger charges has given even lower yields of single crystal material.

The objective of the program was to adapt the Heat Exchanger Method (HEM) for the growth of CdTe ingots and demonstrate controlled solidification. It was shown that the desired convex solid-liquid interface can be developed and its movement can be controlled by controlling the crystal growth parameters.

During the Phase II program presynthesized CdTe meltstock was utilized and 2 inch and 3-inch diameter ingots were grown. It was demonstrated that with controlled solidification by HEM the small grains nucleated in unseeded growth enlarged in size during growth and spurious nucleation was minimized. By controlling the nucleation and growth, only two grains were formed for the 2 inch and 3 inch diameter ingots. Characterization of samples showed improvement in properties of the material as compared to commercially available CdTe. Twin-free bulk samples of approximately 5 cm size could be obtained. Characterization for defects was carried out by etch pit density and values of $10^3/cm^2$ were obtained for HEM grown CdTe compared to $10^5/cm^2$ reported for commercially available material. Semi-insulating samples with a uniform absorption coefficient of approximately 0.03/cm were produced. The quality of the material was limited by the impurities in the meltstock. The potential for further improvement in quality by using high purity starting material exists.

COMPANY: Crystal Systems, Inc.
PHONE: (617) 745-0088
CONTACT: Chandra Khattak

Material Corrosion Inspection by Dual-Energy Radiography

Corrosion of equipment and material costs the Armed Forces billions of dollars each year. A need currently exists for a cost-effective, non-destructive inspection tool able to detect corrosion within military equipment. This project involved the design and construction of a preprototype dual-energy X-ray scanner capable of detecting internal corrosion within material structures. The scanner operates by taking digital radiographs at two different effective X ray energies (hence the term dual-energy) and processing the resulting computer images to obtain detailed material properties of a part, including the location and extent of corrosion damage.

The scanner can handle objects up to 20 inches in diameter and 22 inches in length. The scanner is complete with all necessary computer hardware and software to perform the scans in a very efficient, user friendly manner. Output from the scanner is in the form of a digital array of values which are displayed as different colors on a television monitor. This allows for simple, visual detection of corrosion within parts.

The success of this program demonstrates the utility of dual-energy radiography as an effective corrosion detection tool which can save the military billions of dollars. Through early detection of corrosion, equipment can be repaired more economically, corrosive damage can be minimized, and safe operation of military equipment can be assured The results of this program also have the potential to be applied to many nonmilitary applications where corrosion or contamination of material structures are of concern and detailed internal material property evaluations are needed

COMPANY: Advanced Research & Applications Corp.
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CONTACT: James H. Stanley

Hybrid Fiber Carbon-Carbon Composites for Improved Compatibility with Oxidation Resistant Coatings

Carbon-carbon composite materials exhibit excellent strength properties to very high temperatures, making them ideal candidates for severe environment applications such as turbine engine components, high velocity aircraft, and reusable space vehicles. Unfortunately, carbon-carbon is also susceptible to degradation in these types of applications unless it is protected from exposure to oxygen. Current protection techniques utilize thin ceramic coatings applied to the outer surfaces of carbon-carbon composites. Since the ceramic coatings react to rapid heating and cooling differently than carbon-carbon, such coatings tend to crack and fall off quite readily, thereby exposing the vulnerable carbon carbon

The purpose of this project was to explore an approach to modify the surface of the carbon carbon materials so that a ceramic coating would remain intact and effective for a longer period of time. Different ceramic fibers were incorporated into carbon carbon materials in an attempt to make the composite surfaces match the expansion and contraction behavior of the ceramic coatings during rapid temperature changes. Oxidation testing of coated specimens from these modified carbon carbon materials demonstrated significantly improved resistance to coating failure and material degradation over baseline coated carbon-carbon.

The success of this program has demonstrated that tailoring the thermal expansion properties of the carbon carbon composite surfaces is a viable approach to improving the effectiveness of current protective ceramic coating systems. Further development of this technology offers the potential for near-term use of carbon carbon composites in jet engines as well as air and space structures to increase operating temperatures and therefore efficiencies.

COMPANY: Fiber Materials, Inc.
PHONE: (207) 282-5911
CONTACT: Dr. H. Dean Batha

■ MATERIALS

A Four-Point-Probe Meter for Non-Destructive Measurement of Resistivities of III-V Compound Semiconductors

A new method for employing the Four-Point-Probe technique to measure resistivities of III-V and II-VI compound semiconductors without alloying the contacts has been developed. Some special electronic circuits were invented to enable using DC biases to reduce the noises as well as high resistances of the probe contacts to the semiconductors while using AC to do accurate measurements.

As a result, it extends the range of sheet resistivity measurement from a few thousand ohm per square, which is the upper limit of the existing eddy current method, to more than one hundred thousand ohm per square. Also, the geometric resolution of the measurements is improved from about 2cm to 1mm.

We can feed in these Four Point Probe measured data to the Universal Mapping Program, which is developed by Four Dimensions, Inc., to generate contour maps and 3D maps of ion implanted layers and epitaxial layers of III-V and II-VI semiconductors. These maps provide visual feedback that aid in rapidly identifying malfunctions of process equipment, stability, and processing uniformity.

Markets for this instrument have opened up. Companies such as Harris, Motorola, Hughes and NEC have ordered or are giving orders for the system.

COMPANY: Four Dimensions, Inc.
PHONE: (415) 782-1843
CONTACT: James T.C. Chen

Ordered Polymer Nonlinear Optical Materials

Nonlinear optical effects have emerged at the forefront of research because of their importance in optical signal processing, digital optical switching, and optical logic. The potential speed (subpicosecond) and large bandwidth capability of optical devices, and their capability for parallel processing of information makes optical signal processing and optical computers very attractive. The requirements of all optical signal processing and optical computing require a combination of properties in materials that favor the development of organic and polymeric materials.

The electro optic properties of conjugated polymeric systems such as the ordered polymers result from electronic (^ electronics) transitions rather than physical orientational motion of the molecules or molecular segments. The electro-optic properties resulting from the interaction of light with the electronic transitions in the polymer manifest as the third-order nonlinear susceptibility, ($X^{(3)}$). Material requirements for nonresonant third-order processes are extensive ^delocalization, transparency in the spectral region of interest, a high degree of molecular order, and excellent optical quality of the polymeric material such that there is a minimization of scattering by the incident beam.

Ordered polymers offer the unique advantages of. 1)Liquid crystalline order with the possibility of matching electric field direction to orientation of polymer, 2) Fast response (subpicosecond), 3) Useful optical window for signal processing; 4) High laser damage threshold, and 5) Potential to molecularly engineer properties and process into desired architectures.

This program showed that ordered polymers exceed the limitations of existing inorganic materials such as lithium niobate and potassium hydrogen phosphate. The subject of the program, poly p phenylene benzobisthiazole (PBZT), has high laser damage threshold and a value of $x^{(3)}$ of 2.7 x 10" esu. The environmental stability of PBZT along with its excellent mechanical properties makes it an excellent candidate for opto-electronic device applications.

COMPANY: Foster-Miller, Inc.
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CONTACT: Dr. Mark Druy

Development of an Aluminum Rivet for Use Above 500 Degrees F

Since 1980 the Air Force has funded a significant effort to develop advanced powdered metallurgy aluminum alloys for aerospace structural components at service temperatures up to 800 degrees F. Significant cost and weight savings have been demonstrated when titanium and steel components can be replaced with high temperature aluminum alloys. With the development of suitable alloys and plate rolling and extrusion techniques, component fabrication and testing has begun. The goal of this project is to develop aluminum rivets compatible with these new alloys for component fabrication.

In Phase I of this project, rivets made from a representative alloy were installed and tested. Results showed that achievable improvements in the material properties of ductility and strength would yield a satisfactory rivet. Phase II has three stages. In the first stage, two competing material producers supply Measurement Technology Northwest (MTNW) with a series of rivet stock. Each delivery is quickly evaluated by MTNW, and the results are used to adjust the subsequent material production. In the second stage, the best material from each supplier undergoes complete installation and room temperature static strength testing. In the third stage, materials which have performed satisfactorily in the second stage undergo room temperature dynamic strength testing and elevated temperature static and dynamic strength testing. Additional testing and consulting are provided in the second and third stages by the aerospace manufacturer who is the first end user of this material. The test data is used to choose the best alloy system and as a basis for defining preliminary design joint-allowables.

As of this writing, the first stage is being completed. Preliminary results show project goals for static strength and ductility are met by one material producer, and nearly met by the other. The producer that is short of the project goals has several first stage material improvement iterations remaining.

COMPANY: Measurement Technology Northwest
PHONE: (206) 525-4099
CONTACT: Dr. Peter B. Zieve

High Temperature Heat Pipes for Growth of Semiconductor Crystals

Crystal growth is temperature sensitive. Uniformity can be enhanced, and defects minimized, by providing an environment of constant temperature. This applies both to bulk crystal growth (in Czochralski furnaces) and to layered (epitaxial) growth.

The condensing portion of a heat pipe is inherently constant temperature. We successfully fabricated and tested toroidal heat pipes, filled with magnesium, for use at 1250°C with Czochralski furnaces. We also successfully fabricated and tested heat pipes with flat condensing surfaces, filled with potassium, for use at 700°C with epitaxial crystal growth. The "shell" of both heat pipes is made of TZM, a molybdenum alloy, which can be formed, machined, and welded. Both heat pipes are heated by RF induction.

We will continue to develop flat topped heat pipes (the more marketable configuration) by using safer working fluids and by making them large enough to heat 6" wafers.

COMPANY: Foster-Miller, Inc.
PHONE: (617) 890-3200
CONTACT: Scott Hynek

■ MATERIALS

High Resolution Ultraviolet Filter Development

This Phase II project focused on the design and manufacturing technology for producing optical interference filters that can transmit ultraviolet images (such as missile plumes) and maintain high image resolution while rejecting visible and longer wavelength radiations. Compared to filters presently used, ultraviolet image definition can be substantially improved.

Computer assisted procedures for design of representative filter types is being developed to satisfy desired spectral performance and rejection. Procedures confirm design and fabrication of filters for specific applications, followed by field evaluation. A test facility for measuring resolution performance is assembled and evaluated. Specification objectives for resolution, spectral performance, and out-of-band rejection are expected to be achieved.

Optimal deposition technology is determined and established as the basis for subsequent quantity production. The availability of ultraviolet filters with high quality image resolution benefit propulsion, upper atmosphere, auroral, solar and space studies, weather forecasting, high resolution photography, and many defense applications. We anticipate that the availability of such filters will trigger innovation and create new needs for both government and high technology commercial applications.

COMPANY: MicroCoatings
PHONE: (617) 692-8140
CONTACT: Dr. John C. Simons

High Temperature Resistant, High Strength Plastic Composites

The SBIR Program objectives are to demonstrate new and improved materials and processes that make molecular composites easy to process and use. Fiber filled plastic composites are limited by their low temperature resistance, strength, and failure by the fibers pulling away from the plastic. To solve these problems, the Air Force developed materials called molecular composites.These materials use rigid rod like polymers in place of the fibers in composites.

Although demonstrated successfully in the laboratory, these materials are too difficult to produce or process into commercial products. During Phase I, we demonstrated a new and simpler approach for forming molecular composite materials. To date, in Phase II a new, patentable, synthesis procedure for these materials has been developed that will allow economical scale up for manufacturing. In addition, these materials have been blended with standard matrix materials (epoxies and bismaleimides) to yield homogeneous, tough products. By the end of Phase II, improved rigid rod polymers will also be developed and used to form composites with the new matrix material.

This work will produce commercially viable molecular composites. These materials will be able to replace metals and other composites in high temperature, high stress application such as aircraft.

COMPANY: Brewer Science, Inc.
PHONE: (314) 364-0300
CONTACT: Dr. Terry Brewer

High Power Microfocus X-Ray Tube for Real Time and Computerized Inspection

This research focused upon the construction of a new class of liquid cooled, continuous duty rotating anode x-ray tubes for non-destructive inspection (NDI). This new high average power x-ray tube is expected to have an output power an order of magnitude or greater than currently used fixed anode x-ray tubes. In general, this power increase translates directly into about a 10 X increase in system throughout for computerized and film inspection techniques, and superior images (increased counting statistics for improved contrast) for real time blade or motor inspection systems. This Phase II program designs, develops and demonstrates an experimental liquid cooled rotating anode x-ray tube capable of operating at 4,000 watts, 0.3mm focal spot under simulated NDI conditions while providing a minimum of 500 hours life. The high voltage electron gun design methods developed in the Phase I program are incorporated into the Phase II electron gun. To date, 6 patents (including one European) have been issued covering the technology of this new x-ray tube.

The microfocus electron gun and rotating anode tube is intended for use in continuous duty high throughput X-ray NDI systems which can offer savings in minimizing equipment requirements, more efficient use of personnel, and improved image quality. In factory automation, the real-time measuring and inspection of parts while being machined is possible using a high power x-ray system, whereas current optical techniques are not practical with translucent and undulating cutting fluids.

COMPANY: Coriolis Corporation
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CONTACT: Arthur H. Iverson

Failure Mechanisms in Composite Turbine Blades

In this work we derive two approximate analytical models to describe the stress/strain field within each layer of a rotating turbine blade and hub. At the foundation of the model is the fundamental observation that the very low width to thickness ratio precludes the use of the assumptions of classical lamination theory. Assumptions regarding the response distributions that are consistent with overall equilibrium lead to the appropriate analytical expressions for blades and the radial orthotropy in the hub enables us to derive solutions for stress fields in the hub. Strength predictions are made for three different blade architectures one with orientations used by existing design, second prone to failure and the third not prone to failure for a given spin speed.

The results show that an optimum blade architecture can be determined using these models. A computer algorithm for IBM PC and Macintosh computers are being written using these models for conducting the strength analysis of the turbine blade. Micromechanical models are being developed for predicting the effects of the variation in constituents in the laminate, weave form and the volume fractions of the fiber and the matrix. Because of the complexities associated with the large number of layers, geometric configuration as a twisted blade and edge effects, a composite turbine blade requires the use of approximate modeling techniques.

The best way of effectively achieving this goal is to develop validated computer code which can be used with utmost ease. The work is in progress to accomplish this goal.

COMPANY: Adtech Systems Research, Inc.
PHONE: (513) 878-2774
CONTACT: Som R. Soni

■ AVIONICS

CEESIM/Suppressor Implementation TEEVAL Prototype Development

The historical approach to man-in-the-loop evaluation and training systems has been to first model the system to be evaluated (i.e., an aircraft or threat weapon system), and then build the model stimulation and end-game analysis support resources around it. The design approach devised by Amherst Systems has been to develop the realtime simulation of the total combat environment and implement it in hardware such that many hardware models and operators can be simultaneously interfaced.This approach focuses on the scenario representation and interface technology and not on development of specific weapon or avionic system models.

In response to the need for closed loop simulation systems, Amherst Systems, Inc. is developing, in this project, the Tactics and Equipment Evaluator (TEEVAL). TEEVAL is intended to be a low cost reconfigurable laboratory system which supports operator/equipment-in-the-loop evaluation through the simulation of scenarios with any combination of friendly and hostile players.

These simulated players react in real-time to the actions of the system(s) under test (SUT) through the use of algorithms which model platform capability and actions. The algorithms include the SUPPRESSOR composite mission level model hosted in a software shell which supports realtime interactive model operation. TEEVAL connects to the SUT through interfaces which provide multisenser stimulation. The Combat Electromagnetic Environment Simulator (CEESIM) is used in this operation to provide the pulse-by-pulse digital and RF stimulus. To close the loop, TEEVAL monitors any states of the SUT that can involve simulated platform reaction. These states include SUT emitter and jammer status, firing status and movement status. Multiple systems under test can be interfaced for the evaluation of few-on-many equipment and tactics.

TEEVAL represents a new concept in tactics and equipment evaluation. By fusing the simulation of player actions and the testing of equipment into one real-time process, TEEVAL offers complete man/equipment in-the-loop operation. TEEVAL uses flexible models of confirmed fidelity to simulate player operation and scenario details. This is in contrast to conventional simulators which use a large number of hardware "boxes," each configured to simulate only a particular scenario detail. Hence, TEEVAL also offers greater flexibility and simulation capacity at a much lower cost than conventional simulators. The evaluation setup is also greatly simplified. The TEEVAL operator is spared the task of completely defining the engagement prior to evaluation, saving up to several man-months of effort depending on the scenario complexity. The operator need only describe the individual players and the initial scenario layout. TEEVAL supports this initialization process with a complete workstation environment.

The models used in TEEVAL to simulate the players have dozens of man-years invested in their design and currency. The automatic TEEVAL simulation of players thus features a greater knowledge base than the conventional manual process.

COMPANY: Amherst Systems
PHONE: (716) 631-0610
CONTACT: Cesar Banders

Pilot Loss of Consciousness Monitor "PLOC" for Pilots of High Performance Fighter Aircraft

A Phase II SBIR research and development was undertaken which called for the innovation of a sensor to be used by pilots of high performance fighter aircraft. The sensor would monitor the pilot's eyeblink during high-G maneuvers to determine the possible onset of unconsciousness caused by the maneuver. In the event of pilot loss of consciousness, an alarm signal was to be sent to the aircraft on board computer for further action.

The device which resulted from the research utilized pulsed infrared light reflected from the pilot's eyes. A small fiber optic cable was run from an electronic assembly located beneath the chin of the pilot's oxygen mask. This assembly contained signal processing electronics such as amplifiers and a micro-processor. The cable was routed alongside the nosepiece of the mask and ended about 1.25 inches from the front surface of the pilot's eye. The cable was positioned so as to present no interference with the pilot's vision. Eyeblinks were compared to a stored "template" representing a normal eyeblink. Specific optical and electronic techniques were employed to eliminate false blink indications due to ambient lighting condition.

The device is currently being tested by the Acceleration Effects Laboratory at Wright Patterson Air Force Base. Commercialization of the PLOC sensor itself is dependent upon continued funding by the Air Force, however, there have already been several spin offs from the technology. Specifically, Energy Optics, Inc. has developed two products which utilize blink recognition technology. These products are an eyeblink controlled wheelchair and eyeblink controlled telephone dialer for handicapped persons.

COMPANY: Energy Optics, Inc.
PHONE: (505) 523-4561
CONTACT: John H. Stokes

Solid State Power Modules for EHF Active Aperture Applications

The rapid development of solid state technology makes it possible to build high power Extra High Frequency (EHF) solid state transmitters to replace traveling wave tube amplifiers (TWTA's), particularly for use in spatially combined active aperture antenna systems. The solid state transmitter offers superior reliability and long term graceful degradation capability, when compared to the catastrophic failure modes associated with TWTA's, along with significantly reduced production costs. Field Effect Transistor (FET) and High Electron Mobility Transistors (HEMT) solid state devices have been used successfully for power amplification at lower microwave frequencies (below 20 GHz) with great success, but are severely limited in RF output power at the higher frequencies in the EHF region (above 30 GHz) coming into use today and in the future.

This project has clearly demonstrated that the Impact Avalanche Transit Time (IMPATT) diode (demonstrably the highest power EHF solid state device) can meet the need for a solid state amplifier at these EHF frequencies. In particular, IMPATT power modules operating at 44 gigahertz were designed, fabricated and tested as the transmit power module "building blocks" for each individual radiating element of a spatially combined active aperture antenna system. Each of these power modules provided upwards of 2 watts RF output power over a 2 GHz bandwidth in a compact form factor suitable for antenna element mounting.

In addition, the solid state technology developed under the program can be utilized in other government, commercial applications wherein individual IMPATT power modules can be used as building blocks in either "a single thread" power amplifier or active aperture transmit antenna system and combined to ultimately provide 5, 10, 20 or more watts of power output at frequencies from 15 to 94 gigahertz.

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■ AVIONICS

A Miniature High-Power Battery for Missile Electronics

The electronic packages used in ICBM decoys require a low level of power during the first twenty or thirty minutes of flight, ending with a high power burst during the last few minutes. During early development of electronic decoys, the orginal power source was a two-battery system: one for low-power (a lithium battery) which in turn activated a larger high-power (thermal) battery. The disadvantages of this approach were the substantial volume required by the two batteries, the 3-5 year storage limit of the lithium batteries, and the high heat-discharge into the adjacent electronics package from the thermal battery. The battery represents a significant portion of the decoy volume and weight, and a substantial reduction in size would contribute significantly in efforts to miniaturize the entire system.

Therefore, the goal of the SBIR program was to develop a smaller and improved power source for ICBM electronic decoys without the life-limit and heat discharge problems. During the Phase I SBIR contract, Arias Research Associates studied alternative approaches and proposed a miniaturized reserve battery design based on the lead-fluoroboric acid electrochemical system. The current Phase II SBIR contract is to fully develop this concept, fabricate and test a complete design, and deliver 10 batteries to the Air Force.

The new battery is approximately one-third the size and weight of the previous two-battery approach and quadruples the length of the high-power burst time. The new battery has a storage life of 15 years and thus eliminates periodic "down loading" of the ICBM warheads for battery replacement. The new battery does not discharge any heat into the electronics package and can actually be used as a heat sink to absorb heat and reduce the operating temperature of the electronic circuits.

The new reserve battery offers the potential of replacing other larger batteries in an array of other missile applications. An additional benefit is the low temperature capability (-40°F) not available with many current missile batteries.

COMPANY: Arias Research Associates, Inc.
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CONTACT: Jeffrey L. Arias

Holographic Head-Up Display

Aircraft Heads-Up Displays (HUD) have high priority in fighter aircraft. Advanced applications of HUD's have a need for increased field of view, improved packaging, reduced weight and cost. These needs can be met by new optical designs employing holographic lenses. The development of narrow band CRT phosphors such as P-43 enables the design of an ideal holographic solution to HUD's. Holographic combiners with optical power, in conjunction with these new CRTs have already been demonstrated and have resulted in increased FOV for HUD, without compromising the display and see through efficiencies. These holographic combiners utilized reflection holograms, and acted as a transparent window for the see-through requirement, for most of the spectral range.

APA Optics has completed a Phase I program which analytically proved the feasibility of a complete holographic HUD including combiner and relay optics to provide a low weight and low cost system. This work included the feasibility of using transmission holograms. Further detailed analysis has shown the concept, as implemented by an APA Optics design, to be feasible. Some of the key fabrication issues are currently in development. The Phase II program to fabricate and evaluate a laboratory demonstrator of a Holographic HUD is underway.

The APA optical design has been applied in a proposal for an ATF Integrated Display program. Valuable front panel space previously reserved by packaging constraints for HUD controls has been made available for advanced flat panel displays.

COMPANY: APA Optics, Inc.
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CONTACT: Dr. Anil K. Jain

Real-Time Fuel Tank Ullage Vapor Analyzer

A combat aircraft fuel tank is or is not vulnerable to ignition by enemy gunfire depending upon the percentage of fuel vapor and of oxygen and of inert gas such as nitrogen or Halon in the vapor space over the fuel. It is critical to know these percentages when testing survivability measures; but heretofore there has been no fast, convenient method for measuring them outside the laboratory.

This program has developed an on-line vapor analyzer for the control room of the Air Force Aircraft Survivability Research Facility at Wright-Patterson Air Force Base. It samples the vapor space in a test fuel tank; analyzes for hydrocarbons, Halon, oxygen, and nitrogen; and reports the results to the operator in approximately 60 seconds. The data are presented in numerical form and also plotted on a flammability diagram for instant yes/no determination. The instant read-out enables the test operator to decide on the spot whether to go ahead and shoot, or to stop and adjust the tank vapor composition. A second model is designed for on-board operation to study the "breathing" of an aircraft fuel tank in actual flight.

The instrument is basically a specialized gas chromatograph. Innovations include stabilizing circuitry to all but eliminate warm-up time and environmental effects, cascaded column configurations to separate Halon from total hydrocarbons, and user-friendly software. The initial benefit is the support of aircraft safety research; potential other applications include on-the spot analyses in storage tanks, spill areas, mines, workshops, factories, ship holds—any place where it is urgent to know the detailed composition of perhaps flammable gas mixtures in real time.

COMPANY: Brown J. Associates, Inc.
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Electrical Cone Connector

Present aircraft and missile electrical connectors have a number of problems that can only be solved by a basic new design. The cone electrical connector provides a solution to these problems and can be produced at less cost than present connectors. An example of one major problem of present connectors is the very high engaging and disengaging forces required to mate the male and female connectors, the number of contacts of present connectors must be limited to prevent these high forces. The electrical cone connector has no limit to the number of contacts in one connector, for the engaging and disengaging forces are zero.

E.A.I. developed, designed and fabricated four electrical cone connectors under a U.S. Air Force contract. The male and female connectors consist of many contacts molded in a plastic body. The first connectors were designed and fabricated for 50 contacts. Larger connectors could have 100 to 500 contacts and still have zero engaging and disengaging forces. The cone connector will provide many more contacts in the same volume as present connectors since the contacts are near the outside of the connector, with the locking mechanism in the middle of the connector. Present connectors have the locking method on the outside of the connector while the contacts are near the center of the connector.

Two of the four cone connectors were tested. The cone connectors passed the tests with no problems. The completion of the tests and the final report was the end of the SBIR Phase II program. Many gains and benefits will be realized from the use of the cone connector, but first a specific need for the connector, such as the mating connection between a weapons pylon and an aircraft, which requires many contacts, must be established by the military before Phase III final development and production can be started.

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CONTACT: E.A. Strate

■ AVIONICS

Distributed Kalman Filter Architectures

This SBIR contract investigation has developed distributed Kalman filter architectures applicable to integrated multi-sensor navigation systems for advanced tactical aircraft of the 1990s. In the past, the potential high levels of accuracy and fault tolerance of such systems were not fully realizable by application of classical Kalman filtering (optimal data processing) techniques. The new distributed filtering techniques allow the full potential of these advanced systems to be achieved in terms of accuracy, speed, and fault tolerance.

The new methods apply to decentralized systems with parallel processing capabilities. They accommodate systems with multiple local filters, and provide navigation state estimates that are globally or near-globally optimal, depending upon the information sharing mode and master filter processing rate. The new methods show significant improvements in data throughput (speed), accuracy, fault tolerance, and realtime software simplicity. The methods support several different operating modes, such that different system performance criteria can be emphasized during different mission phases.

The design methodology associated with the new methods can also yield savings in system development and maintenance costs. Program deliverables include proven implementations of the new distributed filtering techniques, so that navigation system designers can take advantage of the associated performance and reliability improvements for current- and next-generation avionics systems.

The results have clear application to integrated multi-sensor navigation systems for advanced tactical aircraft, as well as for ships and land vehicles. They also have potential application to cooperative navigation system operations among the Space Station, Shuttle, and (future) Orbital Maneuvering Vehicle. Commercial applications include satellite tracking systems, geological exploration systems, and other applications requiring optimal combination of information from distributed systems with multiple data sources.

COMPANY: Integrity Systems, Inc.
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ESMS: A Distributed Cooperating Expert System for Pilot Aiding

ESMS stands for Expert System Management System. This work was initiated as an attempt to incorporate expert system technology (smart, intelligent computer) in an advanced fighter cockpit to reduce pilot workloads and increase mission effectiveness. A benefit of this system is that it will anticipate and warn the pilot of an impending problem before conditions become critical, and it will aide the pilot in analyzing and prioritizing critical problems when more than one occurs simultaneously.

As opposed to a traditional expert system residing on a single computer, ESMS is a set of distributed cooperating expert systems running on separate multiple computers. Each of these systems is responsible for its own area of expertise and together they cooperate to aide the pilot in real time threat evidence, route planning, weapon selection and information flow management.

UFA has successfully designed and developed an architecture to coordinate the interactions of these expert systems which may be geographically distributed, and it allows the ESMS to access real time flight and terrain data for time critical decision making. This architecture is of considerable interest to the Air Force for pilot aiding. However, it can also be used for other commercial and industrial domains involving distributed real time data and real time decision making, such as a manufacturing setting.

COMPANY: UFA, Inc.
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Laser Fiber Optic Sensor for Human Biomagnetic Measurements

Functional abnormalities of the human heart and brain responding to severe physiological conditions can be revealed through magnetocardiography (MCG) and magnetoencephalography (MFG). The biomagnetic field magnitudes are very small, on the order of 10^{-10} and 10^{-14} Tesla for MCG and MFG, respectively. Presently these very weak fields are measured using cryogenic magnetometers based on the superconducting quantum interference device (SQUID) which is usually limited to laboratory use. To permit the evaluation of human biomagnetic fields under noninvasive conditions, this program involves the development of low-cost, compact, room temperature, sensitive magnetometers based on fiber optic interferometric sensing technology.

The Air Force recognizes benefits from a biomagnetic sensor that permits continuous monitoring of the physiological condition of night personnel such as fighter pilots during combat assignments and high g maneuvers. Such an optical sensor measures the magnetic signals generated by the heart and brain as indicators of pilot workload, overload, stress and blackout. Multiplexed arrays of these miniaturized sensors are placed in the pilot jacket or helmet and are operated in normal cockpit environments.

During the Phase I SBIR program, fiber optic interferometers with magnetostrictive magnetic field sensing elements were designed and the feasibility of using such measurement techniques was demonstrated. The overall objective of the Phase II program is the development of a reliable fiber optic magnetometer to measure magnetic fields emanating from organs of the human body. The program establishs technical specifications for prototype engineering models to be fabricated during the Phase III program. In addition to military applications, potential commercial applications include magnetic sensing for clinical cardiology and neurology, as well as geomagnetic field mapping, geological exploration and nondestructive testing of materials.

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Coherent Infrared Fiber Optic Image Bundle for Aircraft IR Imaging Systems

The exact placement and packaging of infrared imaging sensors aboard high performance aircraft is limited by concerns for aircraft radar cross section, aircraft aerodynamics and the fact that each sensor must be close coupled to its mated detector, Dewar module. Present technology limits the ability to transmit IR light signals from optics to an image detector. A newly developed fiber optic system showed feasibility of transmitting IR images through a 2 meter, coherent, fiber optic bundle made from heavy metal fluoride glass. A second system will demonstrate an IR imaging system operating in the 3 to 5 um atmospheric window using a 5 meter coherent fiber optic bundle between the entrance aperture and the detector, Dewar. Results of this demonstration program will provide the necessary information required to configure a complete system for flight testing.

Coherent bundles of heavy metal fluoride glass fibers will allow the transmission of image quality IR information from a number of remotely located sensors to centrally located detector, Dewars. This will lead to the economic use of these systems in a wide variety of applications for industrial process control, robotics, medical diagnostics, and military IR vision systems, as well as the primary goal of improved aircraft systems.

COMPANY: Foster-Miller, Inc.
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■ AVIONICS

Development of a Dynamic Feedback System to Control Instabilities Within Liquid Rocket Engines

Rocket engine designers have had considerable success in using Helmholtz resonators to control combustion instabilities within liquid rocket engines. These devices absorb the small amplitude pressure waves at the beginning of the acoustic feedback process, preventing growth of the waves. A major drawback to these devices, however, is that they absorb sound energy efficiently only over narrow frequency ranges centered at their natural tuned frequencies. Often, large numbers of these devices must be used to absorb even a modest frequency range of undesired sound.

Research is being conducted to apply adaptive filter control theory (i.e., active control) to Helmholtz resonators to extend the frequency range over which they efficiently absorb sound. Control algorithms were developed to maximize the resonator sound absorption bandwidth. The utility and value of this approach was verified experimentally by installing a Helmholtz resonator in an impedance tube and measuring its absorption bandwidth with and without active control. Tests indicated that the actively controlled resonator achieved excellent sound absorption over the entire frequency range tested—thus behaving as a highly efficient broadband sound absorber! These results are very important and demonstrate the practicality of applying active control to Helmholtz resonators. This scheme can be easily extended to absorb sound consisting of multiple tones of different frequencies and amplitudes.

In addition to its application to control combustion instabilities in liquid rocket engines, the technology can also be used in very low frequency sound and vibration applications. Examples of these applications include (1) the control of reverberant sound in concert, machinery and anechoic rooms, (2) the enhancement of transmission losses in walls, (3) the control of duct noise generated from air conditioning blowers, and (4) the control of vibrational disturbances disrupting operation of optical equipment or sensitive electronic equipment.

COMPANY: Hersh Acoustical Engineering, Inc.
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Improvement of Head-Up Display Standards

Head up displays (HUDs) present flight instrument data in the pilot's forward view. While HUDs were developed for weapon aiming, they permit the pilot to fly using real world cues and synthetic instrument data simultaneously. A lack of standardization has limited the use of HUDs as primary flight references. In addition, HUDs have come under attack recently as contributing to spatial disorientation.

This project developed a design guide for HUDs and analyzed the safety issues of flight by reference to HUD symbology. While past and current HUD research programs were used in the development of this guide and safety assessment, flight and simulation experiments were flown to obtain specific data not otherwise available.

Approximately sixty hours were flown in a variable stability NT 33 using a programmable HUD. The results were used to define control delay specifications and HUD accuracy requirements for landing approaches. In addition, a number of HUD symbologies were evaluated in a fixed base simulator to measure their effect during unusual attitude recoveries. A number of HUD improvements to enhance unusual attitude recovery have been made.

The project concluded that HUDs are suitable for use as a primary flight display, but that current military HUD training is inadequate. Reported HUD problems are exasperated by the lack of adequate training. A generic HUD procedures trainer is highly recommended to correct this problem.

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Improved Thermal-Oxidative-Deposition Screening Tests for Turbine Oils

Current MIL-L-7808 qualification procedures for turbine oils rely on laboratory bench, jet engine simulator, and full scale jet engine tests to evaluate engine oil performance capabilities. The laboratory bench and engine simulator tests can take several months to complete and cost as much as $100,000. The results are somewhat qualitative in nature and do not always accurately predict performance in the full scale engine test or in operational engines. Thus, a rapid and easy to use test method that accurately simulates the high temperature lubricant degradation phenomena in operational engines and which provides quantitive differentiation of turbine oils based on measurable physical quantities is desired.

Simple, repeatable thermo-gravimetric analysis (TGA) and differential scanning calorimetry (DSC) test procedures capable of discriminating the thermal-oxidative-deposition (TOD) properties of turbine oils have been developed in this program. A large data base and associated understanding of the influence of oil sample size, oil additive concentration, heating rate, metal catalyst, oxygen pressure, and oxygen flow rate was developed during the program. A ranking method to differentiate oils based on TGA/DSC volatility, oxidation, and deposition results (called VOXDEP) was applied to both candidate and qualified MIL-L-7808 oils. Without prior knowledge VOXDEP correctly predicted, based on tests taking one hour, that a particular candidate oil which had successfully passed the laboratory and engine simulator test would fail the full scale engine test. Mass chromatography was used to monitor the changes in lubricant chemistry of a model oil as thermal degradation progressed. These data provided the basis for correlating TGA/DSC results with current MIL-SPEC bench tests, engine simulator tests, and actual engine results.

The research from this project has resulted in the development of TGA/DSC techniques that can: 1) Establish lower limits for acceptable volatility, oxidation and deposition (VOXDEP) characteristics of turbine engine oils (these criteria could be a valuable addition to the current MIL-SPEC test); 2) Discriminate between qualified engine oils as well as aid the development of new, higher performance formulations; and 3) Predict the remaining useful life of aged turbine oils.

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Traction Modeling of Military Lubricants

Rheological behavior of a lubricant in concentrated contacts plays a major role in overall performance of intricate mechanical components such as bearings, gears and transmissions. A realistic modeling of lubricant behavior is essential for both design of mechanical components and development of required lubricants for a prescribed operating environment.

In the first phase of this project, Newtonian models were considered to develop a semi-empirical approach to modeling the traction behavior of two military lubricants. Coefficients for the models are determined by carrying out a nonlinear least-squared analysis of available experimental traction data. The effectiveness of the modeling approach is demonstrated by incorporating the lubricant traction model in bearing dynamics computer code and by carrying out bearing performance simulations as a function of the model coefficients.

After demonstrating the overall feasibility of the development approach, the current Phase II effort was directed towards extensive model enhancements to simulate non-Newtonian behavior, thermal effects in lubricant films, and surface roughness effects under extreme conditions of operation. The development approach consists of the derivation of significant constitutive coefficients from correlations of the predicted behavior to experimental traction data. It is expected that the current effort shall result in rigorous analytical formulations, necessary computer codes, experimental validation of the various models, incorporation of the model in a bearing dynamics computer program and simulation of rolling bearing as a function of lubricant behavior. The predictive strengths of the models over extended range of operating conditions shall be proven by experimental validation both in terms of prediction of traction in an individual contact and overall performance of a rolling bearing. Aside from enhancement of the current understanding of rheological behavior of lubricants in concentrated contacts, the current effort shall result in computer codes which may have significant potential for the design of mechanical components and lubricant development.

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■ AEROPROPULSION

Experiments and Modeling of Multi-Component Fuel Behavior in Combustion

An experimental and theoretical program has been performed to develop a database and modeling capabilities to relate soot formation from jet fuels to the properties of the fuel. The method of approach to studying soot formation was to perform well-instrumented studies under pyrolysis conditions where variables such as temperature, pressure, reaction time and hydrogen or oxygen concentration were controlled. The fuel properties were characterized by quantitative FT-IR analysis.

Key accomplishments in this program included the creation of database of detailed pyrolysis measurements on a large number of fuels, including several high density, aromatic fuels. Temperature varied from 800°C to 1500°C, pressures from 1 to 15 atm and residence times from 100 ms to 1 sec. A key conclusion of this study was that in almost all cases the fuels decomposed to form a limited number of small species prior to the onset of sooting. Using the FT-IR spectra of the fuels, a factor analysis correlation was performed which showed that the complex IR spectra of the hydrocarbon could be characterized by a few factors. These factors could be used to predict the sooting properties of the fuels at a specific condition. To relate the soot formation to the fuel properties under arbitrary conditions a hydrocarbon cracking model was developed.

This model predicts the decomposition of long chain aliphatics into small molecules (C_2H_2, C_2H_4, H_2). In addition, a soot formation model based on published free radical mechanisms and rates was implemented and used to predict the growth of the soot precursors from the small molecules produced in pyrolysis. The combination of these models can predict the soot and the intermediate light species of pyrolysis (C_2's, C_3's, C_4's, light aromatics) to within a factor of two in the pyrolysis experiments which were performed. It is expected that the fuel characterization procedure and predictive models can be the basis for predicting soot formation in combustion.

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Fuel Neutralization to Prevent Flashback on Aircraft Fires

The objective of the Fuel Neutralization Program was to find a method or additive which would neutralize unburned fuel, during a fire, to prevent it from reigniting. Present methods of extinguishing aircraft fuel fires use aqueous film forming foam (AFFF). The AFFF is primarily a two-dimensional agent which forms a water film on the fuel surface. The mechanism by which AFFF extinguishes fuel fires is double action it provides a blanket to inhibit the supply of oxygen. and also provides an aqueous layer on top of the fuel which decreases fuel evaporation (fuel only burns in gaseous state). When the fuel surface is not flat, such as when the fuel is spilling or running on the terrain; the protective water film, foam blanket is not formed or is broken. Further, when the fuel pours from under the edges of the AFFF blanket or splits the AFFF, re ignition can occur. Since AFFF is widely used by the Air Force, the most desirable methods should be used in conjunction with the AFFF.

The objective of the study conducted was to determine which concepts are the most feasible for fuel neutralization, The most promising concepts include fuel thickening and neutralization by. emulsification with water and, or halon, gelling with gelling agents, solid absorbents and solid inorganic compounds, and the use of chemical kinetic modifying additives. Continuing work in this area includes experimental development of these concepts, with the most promising concepts tested in small-scale fires and the best concept tested in a large-scale aircraft fire.

The anticipated benefits of fuel neutralization is to improve survivability of aircraft personnel in ground fires due to ramp or crash survivable incidents. Commercial benefits can accrue in improved firefighting capabilities for civilian airport firefighting and civilian hydrocarbon firefighting.

COMPANY: Beltran Associates, Inc.
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Structural Enhancement of Solid Propellants

Solid propellant rocket motors for high accelerating missiles, with low burn-out altitude, are more difficult to design due to increased forces resulting from high dynamic pressures, high propellant burning rates and propellant grain deformations. Deformation reduces the port area which can result in increased chamber pressure and failure of the grain due to debonding and tearing. In addition to enhancing the structural parameters, it is desirable to increase the propellant's burning rate and specific impulse. Metals, like aluminum, have been added to solid propellants to improve specific impulse. Usually, metals have been added in powder form, but it is possible to use fibers, wires, foil, and screens of these materials to enhance strength, performance, and burning rate.

The study conducted defined the limits of structural enhancement possible and the loads induced by various mission profiles. Continuing work in this area includes the development of analytical and experimental results for the most promising reinforcement concepts. This work includes further definition of loads and stress analysis of the rocket motors, the design, and tension testing of reinforced propellant and the firing of 2x4 rocket motors. In particular, methods of grain reinforcement utilizing particle size control, isotropic, and anisotropic fiber orientation will be evaluated.

The anticipated benefits of the proposed program are that the structural properties of solid propellants can be greatly increased and/or the inert weight of the motor can be reduced, with the effect that the missile can be subjected to greater performance loads, built with lower take off weight or with increased payload capability. The proposed work is mostly related to military and NASA applications. There are potential commercial applications, since this technology can be used to enhance the structural properties of viscoelastic materials.

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Solid Lubricated Ball/Cage Contact Simulation

Tribology Consultants, Inc. (TCI) designs, manufactures, and markets state-of the-art ball and roller bearings made of technical ceramics, high technology steels, self lubricating plastics, and other recently developed proprietary materials and processes.

Advanced materials, design, lubrication, and computerized process control technology are used to manufacture superior performance products at competitive costs for world markets. TCI's bearing design is a unit-type bearing which can be quickly placed into production without extensive retooling.

Typical applications include. front wheel bearings for cars, high temperature high-speed ceramic bearings for turbine engines, solid lubricated bearings for adiabatic diesel and Stirling engines which are used, among other applications, in the space program, and bearings for a gas turbine engine which will replace the tractor trailer diesel engine.

The latest state of the art solid lubricant materials are being tested in fixtures designed to simulate the ball/cage contact dynamics in high speed ball bearings at high temperature. Performance data from these tests will be incorporated into an advanced computer simulation of bearing behavior, and parametric data will be obtained from which a new design and application engineering methodology for solid lubricated ceramic bearings will be developed.

TCI's components have been tested and have proved their reliability for a wide variety of industrial applications. The company has essentially in place an entire family of bearing products whose performance and low cost far exceed any available bearings now on the market. Continuing R&D, funded by the government and other organizations, will allow the company to retain a 2 to 3 year competitive advantage.

COMPANY: Tribology Consultants, Inc.
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■ AEROPROPULSION

Response Time Testing of Thermocouples in Jet Engine Test Facilities

The project involves development of equipment and procedures for measuring the response times of thermocouples as installed in jet engine test facilities. These thermocouples are used to measure the temperature of the engine components and the media where the engines are installed for performance testing. The performance is tested by operating the engine at simulated flight conditions and making temperature and other measurements to identify and resolve any problem that may interfere with optimum performance of the engine when it is used in a flying aircraft. As the temperatures can change rapidly and since timely temperature information is crucial, an accurate knowledge of response time of thermocouples is important for an effective performance analysis.

The response time of a thermocouple can be measured in a laboratory by exposing the thermocouple to a sudden change in temperature. However, when the thermocouple is installed in a process, its response time will be different due to the effect of installation and process conditions. Therefore, the only way to identify the actual response time of a thermocouple is to test it as installed in the process. This can be done by an innovative technique which has been developed in this project. The technique is called the Loop Current Step Response (LCSR) test. The test is performed by heating the thermocouple with an electric current applied to its extension wires. The current is applied for a specific time period and then cut off. When the current is cut off, the sensor returns to ambient temperature at a rate which is proportional to its response time. The sensor output as it returns to ambient temperature is then analyzed to give the response time of the thermocouple.

The LCSR method was first developed for remote testing of response time of resistance thermometers in the safety system of nuclear power plants. As such, most of the sophisticated analytical and experimental work on development of the method was completed for nuclear applications. This method was then adapted for thermocouples to meet the needs of the Air Force. The feasibility of the method for testing of thermocouples was demonstrated in the first six months of the project referred to as Phase I. In Phase II, the project was expanded for two years to include a variety of thermocouples and test conditions and to develop a final test instrument to provide the Air Force with in-house testing capability. To date, two sets of field tests at AEDC have been completed, in addition to tests at the subsonic and supersonic test facilities at the University of Tennessee in Knoxville, where a cooperative arrangement has been established for this project.

In addition to the Air Force, the capability developed in this project is needed in almost all aerospace and other applications which involve transient temperature measurements. The success of this project provides a useful product with a substantial commercial market. This project has successfully fulfilled the goal of the SBIR project in employment of small businesses to supply the needs of the government and in the meantime develop marketable products for the benefit of the general public.

COMPANY: Analysis and Measurement Services Corporation
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High Temperature Lubricant for Ceramic Bearings

The development of the high temperature gas turbine engine with the super-alloys and technical ceramics requires lubricants that can survive and perform under the same severe environment. To date, the conventional lubricants deteriorate or oxidize well below these extreme conditions. In addition, the prevailing technique in tribology for rolling element bearings is to depend on the solid lubricant-containing separator as a source of transfer film for all sliding and rolling interfaces. This procedure is limiting because surface damage is initiated and accelerated during start-up, prior to film transfer, resulting in early bearing failure.

This research formulated and tested a wide temperature range solid lubricant as a key element for successful bearing performance over a range exceeding 1000°F. The new and novel lubricant is a complex metal chalcogenide. The lubricant displayed properties of oxidation stability, thermal resistance, low shear strength and response to ceramic surfaces.

Wear prevention and functional performance of rolling bearings in the non-fluid regime are dependent on the physico-chemical properties of the lubricant and bearing, including the presence of adherent boundary films in the zones of sliding and rolling contact. This concept emphasizes life controlling characteristics, especially surface response at critical interfaces, i.e., the bearing ringland and separator. The interaction of the solid lubricant and bearing at these critical interfaces is the major factor in life extension for rolling bearing applications.

Six self-contained thin film solid lubricated ceramic bearing tests were conducted in a high temperature bearing rig in the range of 1000°-1500°F, 40,000-50,000 rpm, and thrust loads of 300 lbs. The major results of this work demonstrated (1) the lubricated ceramic bearings survived the severe high temperature bearing test up to six hours, and (2) the complex metal chalcogenide is an effective lubricant for high temperature and high speed ceramic bearings. These results suggest that the interdependent concept and the new lubricant can be a vital approach to the self-contained lubricated ceramic rolling bearings to all high temperature machinery having the critical requirement for long life, thermal stable solid lubricant.

Major impacts include the commercial and military application of the self contained lubricated ceramic bearing to the high temperature gas turbine engine in aircraft. This application to the advanced turbine engine can be beneficial by diminishing the cooling requirements and eliminating the recirculating oil systems. The projected benefits by the engine design simplification are the reduction of the engine's fuel usage, weight, maintenance and cost.

The self-contained lubricated bearing can be applied to machinery in mining, chemical processing and electrical power industries. A unique benefit of the self contained lubricated bearing is its immediate operational readiness after long periods of storage.

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■ C3I

Block-Oriented Networks Simulator (BONeS)

Simulation plays an important role in the modeling, analysis, and design of communication networks. While there are many software packages currently available for simulation-based analysis and design of communication networks, none of these packages provide an integrated, visual, hierarchical framework.

The Block-Oriented Network Simulator (BONeS) may be viewed as an integrated system that provides a complete graphical environment for the description and simulation of communications networks. The integrated environment of BONeS includes the capability to describe protocol functions, layers of the ISO model, and network transmission effects in a hierarchical fashion using block diagrams; configure and execute a discrete event simulation of the network; perform design iterations; and analyze the system performance. Each of these capabilities is provided through a consistent user interface that relies on the extensive use of graphics, windows, and consistency checking to provide a visual environment for describing networks and their protocols. The environment makes extensive use of software engineering, workstation technology, and expert systems to provide an intelligent, user friendly and flexible tool for simulating communication networks.

COMPANY: Camdisco/ST*AR Corporation
PHONE: (913) 841-1283
CONTACT: Dr. K. Sam Shanmugan

Antisimulation for Penetration Aids

The research in Phase I has resulted in novel tactics that significantly improve the credibility of penetration aids. Antisimulation tactics provide the offense designer with additional degrees of freedom to improve penetration aid credibility that are not available with the simulation tactic. We define antisimulation as any change to reentry vehicles (RVs) and penetration aids that improves the credibility of penaids. The aim of the Phase I research was to investigate antisimulation tactics applied to the surface optical properties of RVs and decoys. These tactics require minimum modifications of the targets and could be highly cost effective. We studied bare, unshrouded RVs along with dynamically matched, lightweight replica decoys.

Our approach consisted of varying the solar absorptivity (/a/) and infrared emissivity (/E/) in order to match the decoy and RV distributions of radiances in three LWIR bands. We have shown that by using simulation tactics with the optimal /a/,/E/ values, almost perfect credibility can be obtained for a particular time of day and a particular value of earth albedo. However, if the targets are deployed at different times of day, their performance deteriorates significantly. This sensitivity of the simulation tactics has lead us to formulate the following antisimulation tactic: vary the solar absorptivity and infrared emissivity randomly and independently in different bands, according to distributions which are the same for the RV and the decoy. This reduces the sensitivity of the performance to the time of day, season, and albedo variation. In addition, the independent variations of /E/ in different wavebands adds credibility since it destroys the relationship between target temperature and ratios of radiances in different wavebands (the "apparent temperature" as seen by the sensor). This tactic resulted in almost perfect credibility throughout all the daytime illumination conditions.

The credibility problem at nighttime and during the terminator crossings are due to the different cooling rates of the RVs and decoys. In order to reduce this difference without creating additional discriminants, we have suggested another antisimulation tactic: alter the RV and decoys emissivities in the unobserved bands. A larger RV emissivity will increase the cooling rate of the RV, while a smaller decoy emissivity will decrease the cooling rate of the decoy. (This tactic is similar to reducing a targets radar cross section by emitting radiation in a backward direction.) It has resulted in a significant further improvement.

The ongoing Phase II research is concentrated in three areas. offense use of antisimulation tactics to deny the prior knowledge to the defense by creating multiple classes of targets, materials and technologies to implement these tactics, and defense responses using adaptive discrimination techniques implemented using novel types of neural networks.

COMPANY: Nichols Research Corp.
PHONE: (617) 246-4200
CONTACT: Dr. William H. Schoendorf

Smart-Mux for Transmitting Non-Standard Data Rates via Digital Microwave Systems

The Air Force has a requirement to transmit telemetry data at rates higher than can be accommodated conveniently by existing range digital communications systems using standard data rate at 1.544 Mbps. Present telemetry data rates extend to 1.8 Mbps and are projected to reach 2.2 Mbps in the near future. These high data rates are presently being transmitted by an expensive method of separate and unique transmission facilities, analog radios equipped with filters and voltage-controlled-oscillators. It is desirable to transmit this telemetry data using existing digital microwave radios for improved transmission efficiency and reliability. Commercial off-the-shelf multiplexer equipment developed in North America usually follows the digital hierarchy established by the Bell System that uses standard data rates. A typical multiplexer system may consist of a Level-1 multiplexer that combines twenty-four 84 Kbps standard PCM data channels into one T1 channel, a Level-2 multiplexer that produces one DS2 output for four T1 inputs, and a Level-3 multiplexer which generates one DS3 output for seven DS2 inputs. Many military communication systems require transmitting data at other rates up to 2.2 Mbps. Currently, equipment is not available to multiplex one or more of the high rate data streams for transmission over digital microwave systems. The program objective is to develop a smart multiplexer for transmitting the high rate data streams over digital microwave systems utilizing two or more T1 lines.

Generally it is very difficult to design equipment for variable data rates because of the large amount of combinations that input data can be multiplexed into the output data stream. The mux must be "smart" enough to adapt automatically to each input data date, and connect it to the output when the transmission channel is available or to store the data when the output channel is occupied. Design problems include the detection of input data rates, providing sufficient data storage so that data integrity can be maintained, and to maximize transmission efficiency so that more input data can be transmitted for any given output channel. Many advance signal processing techniques such as automatic data rate measurement, microprocessor (uP) controlled data routing, and word-stuffing have been incorporated into this innovative smart-mux design to accommodate the variable input data rates.

This design concept will benefit future data communication system and permit a variety of terminals operating at different data rates to access the multiplexer. As an example, the input of a multiplexer in a telephone data system can be accessed by many user terminals through the same phone number in a dial network. Since users have different data rates, the multiplexer must adapt to each user as the calls are answered. Data transmission between computers in a local-area-network also have the same problem and can use this smart-mux design concept to accommodate a wide variety of input data rates.

COMPANY: PI, Inc.
PHONE: (213) 370-9961
CONTACT: Dr. Raymond Cheung

Implications of Open Data Releases on U.S. Strategic Systems

Open literature sources such as technical journals, trade magazines and newspapers routinely contain information on U.S. strategic missile systems. The information released through these sources when used singly, in combination, or in conjunction with data obtained through monitoring test shots into Kwajalein can be potentially very damaging to the U.S. The objective of this effort was to develop a methodology for assessing the value of such data to an opposing intelligence service and the value to the U.S. of revealing or denying such data on our strategic systems.

Under this program a literature search was conducted to determine the kinds of information which have been released on a representative U.S. missile system and an assessment of the validity of this information. This information was combined with assessments of measurement capabilities against U.S. test shots to determine the overall value of the information to an opposing intelligence service. These results were used to determine the value to the U.S. of revealing/denying such data and to develop a prioritized list of specific data elements which should be closely held.

COMPANY: Nichols Research Corporation
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■ C3I

Adaptive Nulling by Electrical Surface Control of a Reflector Antenna

Antenna null steering is an interference suppression technique that has been effectively used for many years. Conventionally, however, it is possible only with expensive phased array antennas or limited to narrow frequency ranges for reflector antennas. The innovative concept developed by this project allows wideband nulling and simultaneous multiple null forming using inexpensive reflector antennas. The technique is particularly applicable for anti-jam usage in radar systems but it is also useful for eliminating unintentional interference in communications systems.

Phase I of this project has shown that it is feasible and desirable to form nulls using reflective elements mounted on the surface of conventional reflector antennas. Phase II continues the development.

The reflective elements are typically (though not necessarily) grouped into clusters on the reflector surface. The reflective phase of each element is controllable so that the total secondary field of the antenna is controllable. Single and multiple nulls can be formed rapidly. The clusters can be added to existing or new antennas at considerably less cost and better performance (less loss) than phased arrays. Extended applications in addition to null steering include surface distortion correction, rapid beam steering, autotracking, beam shaping, and low radar cross section antennas.

Phase I has shown feasibility through analysis and simulations. Phase II is providing the performance bounds through analysis and experiments.

COMPANY: Computer Science Innovations, Inc.
PHONE: (205) 772-9577
CONTACT: Robert J. White

Signal Processing for Through-the-Earth Communication

Through-the-earth communication (TEC) systems must generally use relatively low data rates because of the high noise levels at low frequencies and the high attenuation of the ground. An integrated signal-processing system can significantly improve the effective signal to noise ratio (SNR), allowing higher data rates, greater depth of operation, smaller transmitters, and/or smaller antennas.

The signal processing system includes nonlinear processing of impulsive noise, adaptive noise cancellation (ANC) using both electric and magnetic field components, maximum likelihood detection (MLD), and decision-aided feedback. The feasibility of this technique is established by simulations in Phase I and processing real multicomponent VLF noise in Phase II.

The experimental TEC receiver includes antenna, analog, and digital segments. The analog segment is a superheterodyne receiver with outboard preamplifiers that produces six sets of analog baseband I and Q outputs. The digital segment is a microcomputer equipped with a coprocessor, A/D converter, and IEEE-488 interface.

The field tests were conducted at the GMRR laboratory and two sites in rural Vermont. Each test consisted of a number of recordings and real time analyses of VLF noise. The analyses include spectrum, impulsivity, covariance, ANC gain, direction-of-arrival, and bit-error-rate characteristics.

MLD alone is not especially effective. ANC significantly increases the effective SNR, typically by 10 to 20 dB. ANC and MLD together produce a robust signal processing system that further improves the effective SNR by about 4 dB. The combined 10 to 24 dB improvement in SNR allows significant increases in the data rate and/or depth of operation. It also makes possible significant decreases (factor of 10 to 200) in the transmitter power and antenna size.

COMPANY: Green Mountain Radio Research Company
PHONE: (802) 655-9670
CONTACT: Frederick H. Raab, Ph.D.

Innovative High Volume Production Testing of MMIC's

During this Phase II SBIR program, Microwave Monolithics Incorporated (MMInc.) expanded on its in-process testing methodology developed in Phase I and experimentally verified key aspects of the approach. The cornerstone of this approach is the prediction of final RF performance of MMICs from in-process DC/Low Frequency wafer probe measurements throughout the process. For discrete small signal GaAs FETs, gain and noise figure predictions have consistently been within 5% of ultimately measured performance, often within 2%. Equally important, performance predictions for FETs with moderate and even severe deficiencies have also consistently fallen in the same accuracy range. Gain predictions for X-Band MMIC amplifiers covering the 7.9 to 8.4 GHz SATCOM band have been accurate within just tenths of a decibel both in-band and throughout the upper and lower skirts of the response curve. Even for severely defective parts, estimates were within 2 dB across and beyond the band. Both "good" and "bad" MMIC distributed amplifiers covering the 2 to 18 GHz band have also been evaluated, and predicted gains were routinely accurate within 0.5 dB. Within MMInc.'s limited experience, no cases have been observed whereby clearly unacceptable parts were predicted to be good, or where RF good parts were predicted clearly unacceptable. Discrete GaAs power FETs have also been examined, and as expected, linear gain prediction accuracy was the same as for small signal FETs (5%). More exciting, output power for 1.3 and 2.3 Watt power GaAs FET cells was also accurate within 5% for "good" devices, and within 8% for the "bad".

Therefore, under MMInc.'s high volume in-process testing methodology, RF performance predictions based on DC/low frequency probe measurements conducted with a minimum adverse impact on ultimate yield can be utilized throughout the processing sequence to 1) cull bad wafers at the earliest possible point in fabrication, 2) enhance wafer yield via minor circuit adjustments for subsequent processing steps, 3) control process integrity by immediate detection and correction of process drift and abnormalities, 4) minimize on-wafer RF testing, which is nearly impossible for high power circuitry, and 5) minimize assembly of "bad" MMIC chips into packages/carriers for RF evaluation.

An OEM supplied medium power amplifier design was also successfully correlated to DC/Low Frequency measurements during this program, and the design was modified by MMInc. to accommodate an MMIC compatible ion implanted power FET and the newly developed in process testing methodology. Predicted output power in excess of 5 watts in the 5 to 6 GHz band makes this amplifier a potential second source for the OEM design.

COMPANY: Microwave Monolithics, Inc.
PHONE: (805) 584-6642
CONTACT: Daniel R. Ch'en

Personnel Identification Entry Access Control Device

The Air Force expressed a need for a rapid, reliable device for controlling entry access to a restricted area. Our Phase I feasibility research demonstrated that an identity verification device based on shapes and sizes of the fingers would meet this need In Phase II we constructed the Mark III R&D Model of the identity verifier device, which, under program control, can change from the enrollment mode to the entry access mode. To enroll, the authorized person inserts a blank I D card into a card reader/writer and places a hand on a backlighted panel. A solid-state camera senses the silhouettes of four fingers, which the card writer records electronically as template data on the I.D. card. To gain entry access, the person inserts the card into the card reader/writer, which now functions as a card reader. The computer compares the template data to the live finger data from the camera. A match score of 1.0 indicates a perfect match. Any match score below a predetermined threshold value triggers a reject decision on a message panel and the computer sends a control signal to a door, turnstile, alarm or other mechanism preventing entry access. The card carries templates of both hands. The computer automatically recognizes which hand the person has presented and retrieves the appropriate template to make the comparison. It takes 10 seconds to make an accept/reject decision with an error rate of 1%.

We are now developing the Mark IV, a pre production device which will have a total transaction time of 3 to 5 seconds The device can be used for entry access to Air Force and other military installations, airports, tarmacs, buildings, vaults, storage areas, government buildings, embassies, computer facilities, automatic teller machines, banks and industrial or commercial sites.

COMPANY: PIDEAC
PHONE: (513) 767-7425
CONTACT: Dr. Charles Colbert

■ C3I

Evaluation of the Permeable Base Transistor for EHF Performance

There is a need in the Air Force for devices capable of operating in excess of 94 GigaHertz (GHz). The Permeable Base Transistor (PBT) is a possible candidate for extremely high frequency (EHF) operations. Gallium arsenide PBTs are currently being fabricated in the U.S. The objective of this project was to conduct a design oriented numerical simulation study in order to evaluate the suitability of the PBT for EHF applications and suggest design modifications to accomplish high frequencies.

A systematic parametric study involving all the design variables was conducted using Scientific Research Associates Semiconductor device modeling computer code. The study provided a window of operating variables capable of yielding high frequencies. The results of the study serve as a design aid, thus reducing the number of experimental trials and the associated costs. In addition, an innovative modification to the existing PBT structure with significant improvement in performance was proposed. This innovation is currently being incorporated in the new PBT structures at Lincoln Laboratories for the Air Force.

COMPANY: Scientific Research Associates, Inc.
PHONE: (203) 659-0333
CONTACT: M. Meyyappan, J.P. Kreskovsky, and H.L. Grubin

Advanced Techniques for CC&D (D&D) Penetration

An expert system called "IVAN" has been developed in prototype form which predicts the plausible presence of enemy denial and deception (D&D) activities. The system concept is to provide to a U.S. intelligence analyst the types of D&D that might be employed by the enemy given specific situational conditions. In this context, the system employs a unique "reverse" enemy perspective. Using multiple interacting knowledge modules the system performs inferencing on knowledge acquired from the operator and on its own self contained knowledge basis.

IVAN considers a variety of specific target nodes. It analyzes these targets for their composite signature potentials by considering the target's type, size, composition, spatial distribution and activity. The target's signatures are assessed against the environmental conditions at a specific battlefield location.

Environmental considerations include the terrain contour and culture, as well as the time of day, and weather conditions. IVAN uses the target and environmental factors to determine the potential "discernability" of the target as a function of signal above noise. Signatures considered include visual, infrared, fixed target radar, moving target radar and sight.

The system contains a sensor model which represents the opposing force (in this case BLUE) reconnaissance capabilities. It considers these capabilities in the context of the situation and the target's potential "discernability" to determine the estimated threat of detection to the target. The system uses the output of these modules (target, environment, and sensors) to consider the applicability of more than a dozen techniques for D&D.

An interface to the inferencing process has been constructed that simplifies data entry by the operator through the use of a hierarchial toggle menu system. The system also employs default reasoning to permit further simplification and control over partial data entry (it will assume an appropriate value if not provided). To further aid the analyst interface, an explanation method has been devised which parses the fired rule caches and aggregates findings in a set of explanation screens for the operator. This feature prevents the operator from having to review a long list of complex rules to determine the basis for IVAN's conclusions.

The system's potentials are now being explored for application to automatic situation assessment, imagery analyst support, and BLUE force deception planning support.

COMPANY: LICA Systems, Inc.
PHONE: (703) 359-0996
CONTACT: Robert K. Cofod

C3I ■

Millimeter Wave Emergency Communications

A key objective of this program is to take a major step toward the implementation of a high quality short range (less than 3Km) millimeter wave emergency communications (MWEC) system. To accomplish this objective, the latest and emerging technologies, communication techniques, hardware, analytical methods and data were used.

MWT, Inc. has selected a frequency band of 62 to 66 GHz for its MWEC radio system. This band is located on the high side of the oxygen absorption band, and utilizes the steepest part of the absorption responses to aid in achieving the desired low probability of intercept (LPI) for the system. Operation in the 62-63 GHz band in clear weather would use nearly 15 dB/km atmospheric absorption due to oxygen. In heavy rain, one would operate in the 65-66 GHz band and use nearly 15 dB/km of attenuation due to rain. The ability to select a frequency band to achieve nearly 15 dB/km of excess link attenuation provides this MWEC system with its inherent LPI capability. This capability is totally independent of modulation format. In fact, in most of the scenarios examined, spread spectrum codes would not be needed.

A customized modem capable of BPSK/QPSK modulations was used to enable the unit to operate at data rates between 9.6 kbps to 1.544 Mbps. The unit incorporates digital signal processing and forward error correction techniques for exceptional error performance. The modem incorporates integral modulator and demodulator synthesizers to provide independent transmit and receive frequency tunability between 52 and 88 MHz. A microprocessor is used to internally control and monitor the modem.

By using the modem digital processor, fast acquisition and tracking algorithms acquire the carrier over a ±30 kHz range. The modem can acquire and maintain carrier synchronization for E/N values as low as 0.0 dB (zero dB). The bit error performance is close to theoretical. Typically the uncoded measured performance is within 0.4 dB of the theoretical value. An additional multirate convolutional encoder and soft decision decoder is incorporated. The bit error rate (BER) is significantly improved when the coding is used.

The MWT, Inc. modem offers a number of flexible user features. These include full front panel controls and display and control via a data interface. The controls include fine and coarse frequency adjusting, power level control and modulation, coding control. Numerous monitors are also available including receive offset frequency, BER and S/N level.

The RF hardware consists of a horn fed lens antenna (13" diameter) and a three level up/down converter system to linearly translate the output (or input) to the modem. Extremely stable oscillators are used. Not heaters are required thus reducing power consumption. A passive quasi-optical repeater was also developed and delivered on this program to examine the effects of repeaters in the link.

COMPANY: Millimeter Wave Technology, Inc.
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CONTACT: Paul Butler

■ COMPUTATIONAL SCIENCES

Ada Operating System Primitives Implemented in Hardware

Phase I defined operating system primitives whose implementation in hardware is feasible and greatly improves performance. These primitives support task management, timer services and memory management. For task management primitives, the payoff was found to be in the application of Ada to embedded real-time systems, such as Avionics, where tasks are switched at high rates. Timer service primitives allow time delays of high resolution/accuracy and cyclic executives, both vital to Avionics software and not provided by the Ada language. Memory management primitives allow memory garbage collection (not required of Ada implementations) so that full-Ada can be used in Avionics software.

Phase II efforts are focused on producing at least one working model of the primitives defined in Phase I. A custom VLSI chip and pc board were designed to function as a microcomputer coprocessor and modification to the Ada run-time environment utilizes the custom hardware. The model verifies the performance improvement predicted in Phase I and demonstrates the feasibility of using Ada for Avionics software.

Phase II provides a working model of an Ada co-processor that will be marketed as a product. Phase II also demonstrates that full-Ada can be used for Avionics with proper hardware support.

Potential commercial applications include Ada co-processors for microprocessor systems used for equipment control, message handling, Avionics etc. for Government and civilian applications.

Ada is a registered trademark of the U.S. Department of Defense.

COMPANY: Integrated Software, Inc.
PHONE: (407) 984-1986
CONTACT: Samuel S. Harbaugh

Innovative Tactics for Air Combat Simulation Air-to-Air Combat Assessment Model (ATACAM)

Multiple vehicle combat analysis is used to assess the combat effectiveness of aircraft systems and develop system requirements. The heart of air combat simulation models is the decision logic (i.e., tactics) used which, in turn, drives the results and sensitivities. Through implementation of an expert system using data driven (i.e., forwardchaining) rule-based reasoning, as the framework for a realistic, naturally structured, and easily adaptable tactics generation module, the ATACAM simulation has achieved improved operational realism and flexibility to accommodate evolving tactics.

ATACAM is designed to represent air combat between multiple flights of aircraft in both the within-visual-range and beyond visual range arenas. Particular emphasis is placed on the simulation of tactical decision-making and situational awareness at the global, flight, and element (or aircraft) level of the combat. The model addresses and provides a solution to a basic challenge in the simulation of many on many aerial combat, namely, the need to implement the nonphysical process of tactical decisionmaking in a realistic verifiable manner that may be developed, critiqued, and modified by operational personnel as well as analysts.

Model outputs include three dimensional flight path plots, time incremented status reports and run and Monte Carlo summary outputs. In addition, an option is available to print at every event/decision a report on the occurrence and the rationale behind it. As configured, the ATACAM simulation provides personnel of the Department of Defense (DoD) and DoD contractors a valuable tool in the design and operational evaluation of airborne weapon systems. Such use covers a wide spectrum of applications, from the planner who needs to assess the utility of a concept and define system requirements, to the designer who wants to perform tradeoff analyses and finally, to the user that needs to better understand system performance.

COMPANY: Analysis & Simulation, Inc. (ANSIM)
PHONE: (716) 632-4932
CONTACT: Paul Patti

Ada Cost Estimating Model

This project has developed an expert system model for estimating software costs. This model incorporates expert opinion, observed behavior, and empirical evidence to provide a complete analysis of the software lifecycle. The model explicitly addresses all significant aspects of the software development process. Although the model is very complex as a result of its granularity, artificial intelligence techniques are used to simplify the user interface. The result is a model that is extremely accurate and sensitive while being user friendly.

Information is specified in terms which the user is likely to understand. Questions are asked about the number of menus or type of system architecture rather than lines of code or complexity. The model also estimates support tasks, such as quality assurance, and supports multiple development standards. Users may supply as little or as much data as is available. Expert rules are used to fill in where details are lacking.

The model calculates costs for entities called archetypes. Each archetype represents a specific function, for example, menus or external interfaces. The model calculates the cost for each archetype for each activity. An activity is a specific part of the software lifecycle, such as coding or system integration. All factors in the model have values specific to a particular archetype and activity, providing increased accuracy. Activities are combined into phases to provide output specific to the development standard which is being used.

The user interface is menu/window oriented. Output from the model can be tabular reports or graphic displays, selectable by task, by phase, by month, or by combinations of the three. The user can save and restore information from prior modeling efforts.

This model provides the Air Force with a more accurate method of estimating software costs, being able to estimate use of Ada and other modern software engineering methodologies.

COMPANY: Institute for Systems Analysis
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CONTACT: Dr. David S. Alberts

Electron Trapping Optical Read/Write/Erase Memory

This project concerns an erasable optical disk memory approach which is inherently amenable to multi level digital or analog optical mass data storage. Efforts during the Phase I program with materials recently developed by Quantex showed that some of its new electron-trapping materials (ETTM) can provide all optical WRITE, READ and ERASE memory functions which are linear over orders of magnitude of the WRITE energy deposition. Each microscopic storage location could therefore store many bits of information. The operating principle is to optically excite electrons with visible-wavelength light and have them store in electronic traps indefinitely. Near infrared from a laser diode can free some trapped electrons and let them release visible-light for readout, or empty all traps to erase.

The basic materials feasibility of ETTM optical memory media was shown in Phase I. The Phase II effort is directed to generating high-resolution thin-film ETTM memory media on 130 mm optical disks and characterizing their capabilities on an optical disk testbed drive. Disks are being generated and a rotating disk optical testbed has been built

Continuation to the commercialization-readiness stage could bring about the realization of a new generation of optical mass data storage capability for extremely high storage density erasable optical disk memory systems. Extremely high density optical memories with very fast response times could aid numerous DoD systems. Commercial applications ranging from personal computers to large top-end systems are an enormous market area. In preparation for the Phase III commercialization stage, Quantex started another company for erasable optical storage disks and drive systems, and obtained its first-round venture capital financing. Their parallel efforts are preparing for the commercial development as Phase II proceeds.

COMPANY: Quantex Corp.
PHONE: (301) 258-2701
CONTACT: Charles Y. Wrigley

■ COMPUTATIONAL SCIENCES

Eliciting and Structuring Expert Judgment in S/V Analysis

It is essential that the Air Force be able to predict the Survivability and Vulnerability (S/V) of structures and their contents exposed to various types of blast and shock waves. Direct testing is time-consuming, expensive, and often not feasible. Formal simulation models are difficult to run and it is hard to train structural engineers to perform and interpret these models.

The primary objective of Phase II was to provide training to new structural engineers by extending the Phase I Comparison-Based prediction (CBP) application in three areas: (a) development of an expert system for retrieving prior cases that match new configurations and can help guide the analyses; (b) refinement of the CBP method for eliciting information from domain experts; and (c) development of a case-based training program for structural engineers. All three objectives were accomplished successfully, and the Air Force Weapons Laboratory has a new training system.

The key product developed under this project was a case-based training system that runs on a Zenith 286 computer and takes advantage of existing data bases. This system is a model for the development of case-based training in other domains. A second product is a prototype case-based reasoning system that is possibly the first to be built and a military application.

COMPANY: Klein Associates, Inc.
PHONE: (513) 767-2691
CONTACT: Gary A. Klein

Automatic Derivation of Performance Constraints and Generation of Design Guidelines

Embedded computer applications demand high performance beyond current capabilities. Design inadequacies are measured by the difference between actual and optimum performance of application benchmarks on hardware. Embedded computer designers are offered a comprehensive new tool set with the Integrated Design Automation System (IDAS), a Computer Aided Design (CAD) system. IDAS provides optimization of hardware and/or software designs based upon data derived from compiling Ada programs into microcode for a processor architecture expressed in VHSIC Hardware Description Language (VHDL).

IDAS capabilities have been extended and automated to provide. 1) automatic derivation of design data relating an existing machine architecture to required algorithms expressed in Ada (automatic derivation of architectural changes) to optimize an architecture for required algorithms, 2) automatic derivation of design data showing how well algorithms expressed in Ada make use of a required processor architecture, and 3) automatic organization of the preceeding information for efficient presentation to the designer. An object oriented database has been added to allow selective, hierarchical access to design data. When the user selects a hardware or software design function from user interface menus, a sophisticated control system performs automatic execution of IDAS internal processes among a VAX and PC network.

In military avionics systems, microprogrammed digital signal and data processors are responsible for extracting information from aircraft sensors and for automating aircraft functions. Better processor optimization produces more and/or better sensor information and aircraft automation. A breakthrough approach to processor optimization lies in exploitation of resource scheduling data generated during algorithm compilation by the IDAS system. This approach is both generic (applies to all programmable signal and data processors) and quantitative. Since all resource conflict data can be quantitatively analyzed, design tradeoffs can be made with precision. Architecture and algorithm optimizations can potentially be automated. Previously, no generic quantitative approach to automating processor design tradeoffs has been available.

COMPANY: JRS Research Labs, Inc.
PHONE: (714) 974-2201
CONTACT: Robert J. Sheraga

Matrix Signal Processor

Space Tech's Matrix Signal Processor (MSP) provides high-throughput array processing for users of scientific computers. In applications like seismic analysis, radar and sonar beamforming, medical imaging, and finite-element simulation, the MSP can be a tremendous number cruncher, freeing the host computer for other uses. These areas rely heavily on matrix operations, which can easily tie up general-purpose computers for minutes or hours. The MSP relieves the host computer of this burden by taking over the computation-intensive portion of the computer's workload, providing up to 80 MFLOPS (million floating-point operations per second).

By combining high-speed technology with a pipelined parallel architecture, the MSP offers substantial throughput. Four floating-point processors, along with address processors, program-flow processor, and interface processors, ensure that each type of computation can be performed by the correct sub-system. This separation of duties speeds up repetitive calculations such as those associated with matrix and signal-processing operations.

The data-processing section performs real and complex arithmetic on 32 and 64 bit data at up to 80 single-precision MFLOPS or 40 double-precision MFLOPS. The controller and address generator keep track of looping and subroutine execution, which allows the data processor to remain focused on data-oriented operations.The I/O section prepares one bank of memory for processing at the same time that the other bank is being used by the processor.Thus, the data processor never has to bother with I/O operations.

The most common bottleneck of high-performance computers is their connection to the outside world. On the MSP, this bottleneck is eliminated by using a separate processor for I/O. This processor, known as the Vector Processing System (VPS), provides a flexible data-transfer environment designed for high-volume data movement. A 64-bit data bus and two 30-bit address buses allow a single controller to coordinate data flow between any two independent modules. These large buses provide the VPS with an addressable space of 8 Gbytes and a continuous data transfer rate of 160 Mbytes/sec. The VPS lets the user configure the system for multiple hosts, data-acquisition devices, graphics-display modules, additional memory, disk drives, etc. A bus controller arbitrates interrupts and can generate complicated address sequences for all transfers. This powerful central control keeps the interface modules simple; because they do not have to control the bus, the modules need only provide data to the bus.

COMPANY: Space Tech Corporation
PHONE: (303) 223-8166
CONTACT: Michael Andrews

STOF: A Software Verification Tool for Ada Source Code

Current formal verification techniques call for the analysis of system specifications rather than analysis of actual implementation code. This means that analysis is done on an abstraction of a system and therefore may not show results that are correct for the actual system. STOF goes beyond these techniques by formally verifying the actual system source code for correctness, multi level security, and high level design considerations such as path analysis and modularity. Moreover, its input is a combination of a real programming language (Ada) and simple programmer annotations.

In addition, STOF represents a performance improvement that will allow programmers to perform formal software verification during the design and coding cycle. Since STOF can perform most of its analysis very quickly, it should not interfere with the development cycle time.

STOF will offer a high degree of assurance that a software program is both correct and secure. This assurance is needed for applications where software reliability is critical, such as command and control of battle systems.

COMPANY: Compusec, Inc.
PHONE: (619) 260-1881
CONTACT: Margaret Murray

■ HUMAN SYSTEMS TECHNOLOGY

Air Purification Device

Up to the present, general methods of conveniently, completely, and inexpensively removing toxic substances from air have been inadequate. The Electrocinerator™ System overcomes these shortcomings and integrates a highly efficient air scrubber with an electrochemical cell to provide an apparatus which is capable of destroying virtually all toxic chemicals as well as biological substances. A prototype unit sized to clean up 100 cfm of air has been built and tested for the Air Force. Both larger as well as smaller units are feasible, with the smallest units comprising battery operated gas masks for industrial or military applications. Electrocinerator Systems have low operating cost and can be compact, modular in design, and retrofitable into standard ductwork or air-handling manifolds.

These units provide for physical removal of large particles, scrubbing of smaller particles as well as gaseous substances, and incorporate within the single system such destruct methods as solvolysis, complexation and chemical and electrochemical oxidation. Tests with the prototype device demonstrated removal in a single pass of formaldehyde, phenol, acrolein, methanol, toluene, ethylene oxide, dimethylformamide and sulfur dioxide. Other tests showed complete destruction of viruses and bacteria, including influenza virus and staphylococcus aureus.

Projected applications include: military; chemical and food manufacturing plants for destruction, for example, of toxic solvent vapors or maladorous emissions, use in buildings or homes for destruction of toxic buildups of carbon monoxide, nitrogen oxides, formaldehyde, pathogens etc., hospitals, for destruction of ethylene oxide and airborne viruses and bacteria; laboratory fume-hoods in which the contaminated hood air is cleaned and returned to the laboratory and not to the outdoors for increased energy savings, and in subways and on vehicles such as aircraft to eliminate toxic accumulations.

COMPANY: Electrosynthesis Co., Inc.
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Applying Cognitive Principles to Electronic Warfare Training

Current training methodologies are inadequate for training the complex cognitive skills increasingly required in both military and industrial settings. Advances in cognitive science provide new ways of characterizing learning and skill development that are more appropriate for the complex tasks requiring training today than the behavioral constructs on which existing Instructional Systems Development (ISD) procedures were based. This project is developing a cognitive-based task analysis methodology that incorporates concepts and methods from cognitive science with methods from traditional task analysis within the ISD framework. It is intended to provide the basis for developing microcomputer-based trainers for cognitive skill acquisition and maintenance.

A part task trainer addressing principles of electronic countermeasures is being developed using the cognitive based methodology, as a means of evaluating and refining it. The trainer provides methods for assisting students to learn, organize, understand and remember large amounts of technical information by the use of mental models, color graphic visualization aids, game like exercises to encourage memory development and a knowledge base to support what-if exploration.

This cognitive approach provides an improved foundation for the design of low cost part task trainers to train difficult cognitive skills, an important need throughout the military and in industry. These devices can be used for cognitive pretraining, supplementary training, or skill maintenance in the field. When successful, this project could have far reaching impacts on the design or the establishment of requirements for future part task trainers. In addition, the task analysis methodology is applicable to expert system knowledge acquisition and human machine system design efforts.

COMPANY: Pacer Systems, Inc.
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CONTACT: Joan M. Ryder

A Low-Cost, Low-Weight Real-Time Indicator of the Presence of Warfare Gases

The devastating effects of warfare gases (WG) as well as the debilitating effect of the fear of exposure to them, can determine the outcome of a military encounter. It is extremely important to have a simple, small and light weight device that can on site and in a realistic time scale tell the individual military personnel whether or not he is exposed to WG and to which type (nerve gas (NG) or a mustard gas (MG)).

In our preliminary work, in Phase I, we accomplished the following critical objectives. 1) developed a low cost thin wafer, which changes its color from white to red when exposed to concentrations of nerve gas simulants, 2) discovered a new chemistry used to detect and/or to destroy organo phosphorus compounds, and 3) discovered a new structure of color based wafers that can be used to detect trace levels of gases which involves multi layered solid chemistry based layers and membranes.

Production of the NG detection wafer requires precise manufacturing and quality control techniques, part of which we have developed and others we are still perfecting. To our knowledge, no low cost, simple device is currently available that can be used by individual soldiers to detect IN REAL TIME sub lethal concentration of nerve and/or mustard gases. Therefore, the Chromosense™ wafer may prove to be the only available device that individual military personnel may be able to use to determine whether they are attacked by WG and to identify the type of gas that is being used. Moreover, it appears that a noticeable color change appears on the wafer in very short time even when the gas concentration is sub-lethal.

The main objective of the Phase II work is to carry on our initial Phase I findings, to produce a wafer that can be used reliably and consistently by individual military personnel to determine whether they are exposed to nerve or to mustard gases.

The savings that such a detection method may bring in human life and money can not be overstated. However, the potential benefits of this detection method extend way beyond the military needs. Two examples for their use in the civilian market are its potential use for determining the safety of entering agricultural fields after crop dusting with pesticides, and in the area of manufacturing and distribution of pesticides and insecticides. While methods for testing the concentration of phosphorus compounds in fields do exist, the cost for such tests is of the order of $35 75 and thus prohibitive. In addition, these tests require skilled labor, expensive equipment and do not give the results on the spot. In comparison, the costs of a phosphorus compound detection wafer will be of the order of $5 20 each, and every person can use it. Moreover, the Chromosense™ wafer gives the results INSTANTANEOUSLY and on site, and thus, the user can decide on the spot whether the reentry is safe.

COMPANY: Perfect View, Inc.
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CONTACT: A.J. Attar, T. Wilkes

■ HUMAN SYSTEMS TECHNOLOGY

Wearable Emergency Breathing Apparatus Study

Research was conducted leading to the development of a wearable escape unit for use by rocket gantry workers in the case of toxic fuel breakage. The objective is the development of an emergency breathing apparatus which does not interfere with, nor encumber, the worker's activities. The highly toxic nature of current propellants allows response time of only seconds before a worker would be overcome by the toxic vapors resulting from a significant leak. This type of emergency situation is not limited to rocket gantry workers but can also occur in the chemical and mining industries. The best solution to this problem is quick response, i.e., shorten the time needed for the worker to recognize the emergency and don a protective respirator. A respirator prototype is an SCBA using a chlorate candle oxygen source, a sodaline carbon dioxide scrubber, and a fully inclosed transparent hood. All of the SCBA is incorporated into the hard hat, except for the chlorate candle which is mounted on a belt pack.

COMPANY: Abel Company
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Anthropometric Comparisons Between Face Measurements of Men and Women

Since the Nation's armed forces include increasing numbers of female personnel, potential problems in the design and sizing of protective clothing and equipment have become apparent. These problems arise from the fact that most protective equipment and clothing now used by the armed forces were designed specifically for males. The improper fit of clothing and equipment can affect the safety, efficiency and productivity of personnel.

The purpose of the study was to identify differences in the proportionality among face dimensions between sexes which could affect the design and development of an adequate sizing system that will provide a high degree of proper fit for protective face masks. Discriminant analyses were used to identify key dimensions, i.e., face measures which show the greatest proportional differences between sexes, and multiple regression was used to estimate the relationships between the key dimensions identified and other variables important to the proper fit of protective face masks.

In summary, 19 of the 27 mean parameter values were significantly ($p < 0.05$) greater for the males compared to one for the females. The results of the discriminant analyses indicated significant divergence from cross gender anthropometric proportionally. Eleven (40.7%) and 13 (48.1%) variables entered the two models, respectively, with three standardized coefficients greater than 0.500 in each model and two and three negative coefficients, respectively. Overall, the women exhibited proportionally greater interpupillary and pronasale distances and shorter distances for all other measurements. The results of the regression analyses further supported the lack of cross gender proportionality. Neither of the two regression models investigated produced very accurate results especially in the overlap regions of the male and female data sets.

The results of this research indicate that an assumption of anthropometric proportionality between genders is invalid, ruling out the use of a single sizing system for males and females.

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CONTACT: Dr. Barry T. Bates

The Development of a New Chart for Testing Vision: Suprathreshold Contrast Sensitivity

Standard Snellen acuity, a measure of the eye's ability to focus, does not always relate well to everyday visual tasks. Contrast sensitivity, the ability to discern subtle changes in shades of gray, evaluates contrast perception at the retina/brain level and has emerged as a more comprehensive method of measuring visual capability. Current contrast sensitivity tests that are quick, easy to administer, and inexpensive are vision charts that measure contrast thresholds (the minimum levels of contrast necessary to detect objects). Because most visual processing occurs at suprathreshold levels of contrast (levels of contrast that are above threshold), a vision chart that can measure contrast suprathresholds quickly, simply, and inexpensively is needed.

A contrast matching suprathreshold vision chart was developed that measures suprathreshold contrast sensitivity curves. These curves are similar to those obtained with complex, time consuming, and expensive computer video systems previously required for this type of testing. As expected, individual differences between subjects were found when tested with the new chart. The data analysis suggested that the individual differences were due to real differences in suprathreshold contrast perception and not criterion. This result implies that the chart may be relevant to predicting individual task performance at suprathreshold levels.

Suprathreshold contrast perception may be especially relevant in four major ways. The first is the understanding of how an aircraft pilot's perception of contrast relates to his or her visual performance. Large populations of data from pilots can be obtained with the new suprathreshold chart. The second is the development of a suprathreshold model of perception. This is needed for computer simulation and for matching the observer's visual processing capability to displayed and simulated imagery. Understanding how visual channels behave at suprathreshold levels of contrast is the third way the chart can be of significance. Finally, this proposed chart system has additional clinical applications. Pathologies such as amblyopia could be indicated by abnormalities in suprathreshold contrast matching.

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CONTACT: Dr. Arthur P. Ginsburg

Development of a New Composite Material for Use in Protective Clothing

Current protective clothing used by Air Force personnel and others to prevent contact with hazardous vapors is heavy, hot and uncomfortable. Such clothing can be worn only for short time periods before heat stress becomes a problem. There is a need for lightweight, breathable fabric which can provide a safe level of protection against propellant vapors and other toxic organic chemicals. This project has succeeded in developing a multilayer membrane fabric which is permeable to water vapor and impermeable to organic vapors. This fabric has been manufactured in commercial size lots and prototype suits have been constructed and tested. The test suits are comfortable and offer a high degree of protection against hazardous organic vapors. The fabric can be produced at relatively low cost.

COMPANY: Membrane Technology & Research, Inc.
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■ CIVIL & ENVIRONMENTAL ENGINEERING

Continuous Tunnel Lining for Deep Basing

Deep basing facilities must be constructed to resist high loads, therefore the lining structure must exhibit both compliance and toughness to maintain its integrity. Current cast in-place and precast lining systems coupled with the installation of a separate, energy-absorbing backpacking layer are expensive to install, are labor intensive, and are not likely to achieve the 25 ft/hr advance rate goal. To overcome the deficiencies of the current technology a new lining system will be developed which will continuously slipform a two-layer composite lining directly behind a tunnel boring machine at advance rates of at least 25 ft/hr.

In previous slipform development work, advance rate was limited by high drag forces, however, during Phase I it was shown analytically and experimentally that slipform drag is significantly reduced when casting a two layer system. Low drag allows the use of a simple form which can be self advanced using only the force applied by the concrete pump; therefore, no connection to the TBM is required.

The primary goals of the Phase II effort are to develop and test a prototype of the slipforming concept in the full round configuration, and to develop an overall system design specifically addressing the deep base tunnel construction requirements.

Military benefits are centered around the deep basing construction application. Specifically, it will result in a development of a system which can continuously slipform a two layer composite tunnel lining at 25 ft/hr directly behind a tunnel boring machine. The proposed system will produce a better quality lining at a faster rate and lower cost than conventional methods.

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Internal Inspection of Long Tubes

A requirement exists for the precision inspection of Arnold Engineering Development Center Track G test facility to survey for post test damage and/or misalignment of the track rails and for damage to the recovery tube. A preliminary design for a modularized, self contained inspection system with a digital data logger and memory has been developed. The inspection system includes (1) a tractor drive module, (2) a track inspection module, (3) a tube inspection module, and (4) a track maintenance module. This modular approach can be tailored to perform the desired inspection and/or maintenance function at any location in the Track G facility or for its entire length. The tractor driven inspection modules each use linear variable differential transformers (LVDT) to measure accurately the distance between opposing rails (or tube diameters), including localized perturbations greater than ±0.001 inches.

Tests were performed to measure the effectiveness and repeatability of LVDTs on both an actual 10 ft section of track rail and on a rail section with simulated damage. The results of these tests showed that this method is a viable approach to automated inspection to the Range G track and recovery tube sections.

These results should lead to significant cost savings from reduced track inspection time and improvements in the quality and success rate of tests. Additional potential military and commercial applications of this R&D project include (1) internal inspection of rocket nozzles or missile launch tubes, (2) internal inspection of wind tunnels or flow channels, and (3) inspection of kinetic energy rail gun launchers.

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IDLS, A Continuous, Remote Controlled Drilling and Blasting System

The Integrated Drill Load Shoot, or IDLS concept, is a continuous drill and blast rock excavation method based on the use of repeated shots, each comprised of a single blasthole of conventional diameter and depth, all slabbing to a sustained free face. The relatively small size of the individual shots, together with the unique spiral blasting pattern, allows the process to be continuous, even in a tunneling application.

Automation and/or remote control is accomplished by integrating the drilling, loading and shooting functions into a single subsystem, hence the name IDLS. Loading and shooting (initiation) of individual holes is accomplished through the drill steel and bit when the drill is retracted at the conclusion of drilling each hole.

The U.S. Air Force has sponsored the development and proof-of-principle of IDLS for application to underground defense sites, where IDLS advantages include minimized shielding requirements, minimal host rock damage, and flexible excavation geometry. Numerous other mining and civil applications have also been identified.

The first phase experiments involved loading the explosive (ANFO) and the detonator into simulated blastholes through conventional drilling hardware. The rates of loading and the condition of the IDLS loaded explosive were measured quantitatively, then live shots were manually conducted to confirm initiation behavior.

The second phase of the program combines all elements of the IDLS subsystem on a single testbed, with the semi-automated capability to drill, load and shoot a series of holes under remote control. The Phase II tests include live shot sequences in a surface rock quarry.

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Nd:YAG Laser Robotic Workcell for Repairing Jet Engines

The recently completed laser technology application study managed by Hill AFB recommended seven application areas for 400 watt pulsed Nd.YAG laser workcells. Our Phase I SBIR work has carried out and validated the application study recommendations and under Phase II is now advancing the three technology areas necessary to make the production of practical workcells a reality. These areas are. vision guidance, realtime robotic control and expert system user interface software. An adaptive 3 D laser based vision system provides the robot guidance. This system provides tracking of both seams and drawn lines on the material surface as well as provides weld geometry to control the welding process. Presently available robot controllers are at least an order of magnitude too slow for realtime seam tracking. The realtime controller being implemented provides 20 microseconds/axis servo update rate required to guide the robot. Nd.YAG laser workcells will be used in an Air Logistic Center (ALC) environment and therefore will be operated by semi skilled operators. The expert system user interface software ensures high quality repairs with training levels compatible with ALC personnel. No knowledge of laser welding technology is required to efficiently operate the workcells.

The Phase II project proves that welds can be made at less cost than at present and with higher quality while using semi skilled operators. In addition, welds previously thought impractical to attempt can be managed by the expert system. The pay back analysis is expected to show that capital costs can be recouped within one year.

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■ CIVIL & ENVIRONMENTAL ENGINEERING

Hydraulic Excavation System for Hard Rock

The development of secure, underground facilities for defense systems requires new techniques of excavating hard rock which overcome the limitations associated with the use of explosives or tunnel boring machines. Conventional drill and blast methods pose a hazard to nearby facilities or personnel through fly rock, dust generation, excessive ground motion and release of toxic fumes. Tunnel boring machines provide cost-effective non-explosive excavation of long, straight, circular tunnels but are inefficient for other excavation geometries.

The hydraulic excavation (HYDREX) system developed during this SBIR project is capable of non-explosive excavation of hard rock in any geometry required. The system is based on a tool which discharges a pulse of extremely high pressure water into a drilled hole. Phase I research demonstrated that the pressures developed by the HYDREX tool are sufficient to fragment hard rock. A prototype excavation system was built in Phase II. The tool was integrated with a drill feed and the entire assembly was mounted on a backhoe arm. Field testing of the prototype HYDREX system was carried out in a hard vocanic rock quarry. These tests demonstrated the system capability by excavating 20,000 pounds of rock to form a tunnel opening. The capital cost of the equipment is low and it may be quickly deployed to meet the needs of a complex tunneling or construction project.

A number of commercial applications for the tool have been identified by including deep level non-explosive mining, urban construction, concrete demolition and boulder fragmentation. A modified version of the HYDREX tool is now being commissioned by the operator of the Three Mile Island nuclear power plant as a means of fragmenting the melt products pooled in the bottom of the reactor vessel.

COMPANY: Flow Research Company
PHONE: (206) 872-8500
CONTACT: Dr. Jack Kolle

A Continuous Explosive Tunneling System

Current methods for constructing underground facilities in rock involve either mechanical breaking of the rock with large, high force producing machinery or drilling a pattern of holes in the rock and then loading with explosives and blasting. Mechanical excavation is normally not suited to Air Force requirements of relatively short tunnels with noncircular cross sections. Conventional drill and blast excavation involves a cumbersome cycle of drilling, loading, blasting and rock removal, all done with separate machinery.

The continuous explosive tunneling system has incorporated the first three functions of drilling, loading and blasting into one module which produces small (.375 inch diameter) holes and thus detonates only very small amounts of explosive at a time. Proper shielding allows the module to be at the point of excavation throughout the cycle. This research project has developed the module, adapted a two component, liquid explosive, developed an initiation method which requires no electric blasting cap and demonstrated the blasting pattern in field tests. Concepts have been developed of complete machines which use the module to create a tunnel.

The Air Force will benefit from this research by now being able to produce short tunnels in any cross section at reduced cost The system has interest from underground excavation contractors and mine operators in producing the normal range of underground excavations and in situations where explosives would not normally be used because of ground vibrations.

COMPANY: Machine Design Engineers, Inc.
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CONTACT: Dennis P. Martin

Automated Inspection System for Hypervelocity Test Track

The hypervelocity test track at Arnold Engineering Development Center's G-Range propels models at speeds up to 20,000 feet per second. The 880-foot-long track is composed of four radially oriented rails housed in a cylindrical tube. An additional 500-foot long, cylindrical recovery tube is used to capture the models. When a model fails, fragments are scattered and may cause damage to the track. If the fragments are not located and removed, and damaged rails repaired, subsequent test shots may fail as well. Previously, the test track could only be inspected manually for damage and fragments, which was time consuming and unreliable.

A Long Tube Inspection System (LTIS) has been developed with a remote inspection vehicle that can automatically traverse the full length of the track and recovery tube and conduct several simultaneous inspections. A miniature video camera allows the operator to view the inside of the track in near-real time while four sensors "feel" for burrs and gouges. A laser based sensor provides a redundant scan of the surface to insure that no flaws are missed. A key feature of the LTIS is the fact that no umbilical cables are used, the length and complexity of the track make umbilicals impractical. All communications to and from the inspection vehicle are accomplished using a high speed laser-based optical link. All data are displayed in near real time on a computer screen, and adjustable threshold alarms notify the operator when a flaw has been located.

A repair vehicle has also been developed to interface with the remote inspection vehicle, this allows minor repairs to be carried out quickly and efficiently. The Long Tube Inspection System is expected to reduce significantly the time and labor required to inspect the test track between two shots. It will also increase the overall reliability of the inspection process and increase track availability.

COMPANY: Flow Research Company
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CONTACT: James L. Doyle

Small-Charge Rapid Excavation System

The excavation of hard rock for both military and commercial applications is usually accomplished with the traditional drill and blast method. Due to the cyclic nature of drill and blast operations (drill, blast, ventilate and muck) excavation rates are limited and equipment utilization is low. A small charge rapid excavation system employing a novel fracture initiation and propagation technique has been demonstrated to be capable of excavating the hardest of rocks at efficiencies (energy per unit volume of rock removed) four to ten times greater than attainable with conventional drill and blast.

Significant enhancements to the concept developed during the research efforts include the use of propellant rather than explosive charges and the design of a device for containing the charges and effectively sealing the shotholes. A rapid excavation machine based upon the novel fracturing concepts and the results of the Phase I and II SBIR research programs would allow for a machine integrating drilling, small charge blasting and mucking to remain at the excavation face during continuous operations. Furthermore, the machine would incorporate robotic control into a smart system capable of optimizing shothole placement and geometry and charge characteristics for specific rock conditions.

The small charge rapid excavation system would be attractive for military (as well as civil) construction operations where sensitive structures, equipment and personnel would be in close proximity to the excavation face. The small charge rapid excavation system would be attractive in selective mining operations where the ore rock could be fragmented and processed separately from the barren country rock. The barren rock could be kept underground and eliminated from the traditional hauling and milling operations.

COMPANY: Sunburst Recovery, Inc.
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CONTACT: Chapman Young

■ CONVENTIONAL ARMAMENT

X-Ray Smear Camera

Explosive ordnance and armor/antiarmor research has indicated a desire to radiographically investigate the dynamics of these phenomena over 20 to 30 microsecond time scales. A conceptual study identified the X-ray pulser as the focal point of system feasibility. A long pulse radiography system has been developed under SBIR Phase I and II programs.

A prototype 500,000 volt, 1000 ampere, 25 microsecond duration X-ray pulser and camera system have been constructed and are under test. The device produces an intense burst of X-rays 1,000 times longer than what is attainable using current flash X-ray technology, and with considerably lower cost. The X-ray pulser system uses a custom built high voltage pulse transformer to extract an electron beam from a multipoint spark gap region. Electrons incident on a tungsten coated tapered graphite rod produces up to 4.6 Rads of X-rays 1 meter from the pulser output window.

An X-ray camera complements the long-pulse radiography source and uses a fast plastic scintillator to convert the X-ray photons to visible light. A modified microchannel plate image intensifier amplifies the scintillator output and a rotating mirror assembly transfers the image to the film emulsion. A 12 centimeter long segment of film is available for a streak image or 3 discrete snapshot frames of component action.

Significant interest in the system has been expressed by several national laboratories and commercial vendors of high-speed cameras. Furthermore, aspects of the plasma physics effects and pulsed power electrical engineering investigated in this project have potential applications in the areas of high power microwaves, particle accelerators, and chemical laser research.

COMPANY: Mission Research Corporation
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CONTACT: Robert J. Richter-Sand

Seeker-to-Target Closure Simulator

Hardware-in-the loop simulation of seekers is essential for test and validation of missiles. Current technologies are inadequate in meeting the requirements of high frame rate, high dynamic range, high radiometric accuracy and large field of view necessary for constructing complex infrared scenes for simulating the seeker-to-target range closure condition A MOS-resistor technology developed recently has succeeded in meeting all these requirements.

Using this technology, 2 dimensional arrays of MOS resistors larger than 128 x 128 have been fabricated on silicon wafers. Each MOS resistor is made thermally isolated from its surroundings and heated by an electric current to emit infrared radiation over a controllable temperature range of 77 1450K. The independent emissions from the MOS-resistors of the array forming the infrared scene are orchestrated and processed by a parallel processor. When this scene is projected onto the seeker, a variety of seeker to target engagement scenarios can be simulated to evaluate the seeker performance The complete MOS resistor simulator system is also capable of multispectral scene simulation in the range of 1-24 micron and programmability for realtime scenario generation and gaming.

A complete turnkey simulator system with array sizes ranging from 128 x 128 to 1024 x 1024 can now be constructed with this technology. Such a system will have wide applications in other fields such as simulation of space surveillance sensor systems, testing of complex mosaic focal array, in night calibration and infrared sensor simulation resulting in considerable saving in test and validation of complex sensor systems.

COMPANY: Electro-Optek Corporation
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Hard Target Penetration Fuze

This project consists of the following tasks: 1) develop a systems architecture for an all-electronic, hard target penetrating bomb fuze, 2) design, test and validate fuze components and subsystems, and 3) build engineering models of the fuze for testing. The technical objectives were. 1) achieve a low production cost and high reliability through integrated electronics, 2) improve safety by eliminating sensitive explosives, 3) satisfy insensitive munitions requirements, 4) eliminate safing pins by deriving arming and firing energy from the environment, and 5) achieve hard target penetration, delayed initiation performance. The delay after impact timing was achieved with a unique thermal timer developed during the Phase I effort. The insensitive munitions requirement was satisfied by using an exploding foil initiator with HNS. An all-electronic safe and arm circuit is used to achieve safety and reliability. Arming and firing energy was developed using a wind generator driven by the bomb motion in the atmosphere.

COMPANY: Quantic Industries, Inc.
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Drag Reduction on 20-mm Telescoping Ammunition Projectiles Utilizing Base Bleed from a Solid Wafer Add-on

Advanced ammunition for 20 mm aircraft cannons achieves high projectile velocities at the gun muzzle utilizing a telescoping configuration. The increased initial kinetic energy of the projectile is, however, rapidly dissipated by aerodynamic drag In order to minimize the kinetic energy loss, base bleed is being evaluated as a mechanism by which base drag is substantially reduced.

The innovation which this research addresses is the addition of a solid propellant wafer to the base of the telescoping round. The wafer is ignited during the gun firing process and generates gas which flows into the projectile wake throughout its flight. The optimum wafer chemical composition and base geometry required to accommodate the base bleed concept has been isolated. In so doing, it was observed that the telescoping round geometry was more conducive to a steady and spatially uniform base bleed flow than the conventional projectile configuration.

As a result of incorporating base bleed into the 20 mm telescoping ammunition round, the kinetic enery losses of the projectile were minimized with negligible increases in cost or changes in the size and mass. The reduced time of flight and increased impact velocity favorably affected the performance of the aircraft cannon system.

COMPANY: Hokenson Co.
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CONTACT: Dr. Gustave J. Hokenson

■ SPACE & MISSILES

Compendium of Reentry Material Property Data

The design of efficient thermal protection systems (TPS) for reentry vehicles requires a model that can accurately predict the combined ablation, erosion behavior and in-depth thermal response of nosetip, heatshield, and antenna window materials. To accomplish the modeling, test data consisting of physical, thermomechanical, ablation and erosion properties are needed. Although a broad range of materials data exists in the literature, integration of the data into a computerized data base is necessary for the interactive design of thermal protection systems through proper material selection and sizing.

Properties of TPS materials, including several classes of carbon-carbon, carbon phenolic and quartz phenolic, have been compiled from unclassified technical documents. The properties are stored and categorized on an IBM compatible PC. A material selection, screening program written in FORTRAN 77 interfaces with the data base to determine the ablation and insulation performance of nosetip, heatshield and antenna window materials for user specified trajectories and vehicle geometries. Allen & Egger's algorithm is used to calculate a ballistic trajectory and aerodynamic boundary conditions are computed along the vehicle surface for both laminar and turbulent flow. The program incorporates the effects of transition and shape change on nosetip recession by correlating test specimen ablation rates and arc heater flowstream parameters with the actual reentry environment.

The screening program selects appropriate material candidates from the data base for further thermostructural analysis using the ACE, ABRES, and modified CMA aerospace codes which determine the surface thermochemistry, ablation, erosion rates, and temperature profiles of the reentry vehicle. The temperature distribution can be coupled with a finite element structural program to determine vehicle survivability.

A computerized compendium of reentry materials allows the designer to perform parametric studies of potential thermal protection systems through an IBM compatible PC. The selection of appropriate materials for specific missions can save on structural weight and cost, allowing for increased performance and heavier payloads.

COMPANY: Fiber Materials, Inc.
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CONTACT: Tom Foreman

High Temperature Optical Properties of Particulates Exhausted from Rockets

The complex index of refraction is a material property which controls the radiative and scattering characteristics of particles. Rocket plumes consist of post combustion gases and particulate, the radiative signature of a rocket plume therefore is controlled by the emission from this flowing gas, particle mixture. Predictive capability for missile signatures relies heavily on numerical simulation of the plume radiation which in turn requires the complex index of refraction of the particulate as an input. This Phase II SBIR program has developed an experimental capability to measure the complex index of refraction of various materials as a function of wavelength and temperature. The measurements are currently in progress. This project represents an expansion of a high temperature, optically based, experimental capability and, in addition to being of continuous interest to the Air Force, has potential application to particle manufacturing technology such as the carbon black industry.

The experimental capability which has been developed at Physical Sciences, Inc. (PSI) consists of three major components. a shock tube, a particle injection system, and an optical diagnostic system. The shock tube is used to produce the required high temperature environment and can produce temperatures from 800K to in excess of 3000K. The particle injection system is used to introduce a small amount of particulate (less than 0.5 gram) into the tube at the optical measurement station. This system produces a uniform cloud which is crucial to the optical measurements. Optical diagnostics for the system consist of emission, extinction, and scattering measurements that span the wavelength range from the vacuum ultraviolet to the long wave infrared. These diagnostics are clustered around eight optical ports which are located at one axial position on the shock tube. An instrument developed for this program which has potential application for a broad variety of problems is an infrared spectrometer which acquires spectra at 150 KHz data rate.

Preliminary results from the experiment indicate a strong temperature dependence of the imaginary portion of the index of refraction between 2000K and 3000K for A1203. In the near future, the data base for the index of refraction of A1203 will be expanded further and compared to measurements of particulate derived from rocket plumes.

COMPANY: Physical Sciences, Inc.
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CONTACT: W.T. Rawlins

High Temperature Oxidation-Resistant Materials for Satellite Applications

The performance of satellite rocket engines is considerably limited by the available materials, which limit maximum operating temperature and lifespan to 2400° F and 10 hours. This program developed the materials and processing technology to fabricate rocket engines able to operate up to 4000° F for a minimum of 10 hours. This 1600° F increase in operating temperature will result in near maximum theoretical performance, making more efficient use of propellant and decreasing overall propellant requirements. This is of significant benefit because propellant is the single heaviest item on most satellites, imposing a weight penalty that increases launch costs. The eventual depletion of the propellant is the primary limiting factor on a satellite's operational lifespan.

The new materials system uses rhenium and iridium, two exotic metals which, although existing in ample quantities, have found little practical use to this point. Rhenium is used as the structural material to provide strength, with an integral internal layer of iridium added for oxidation protection. No process was previously available for fabricating such a complicated structure. This program developed the means for depositing thick, ductile, pore free layers of iridium (which, despite significant effort and expense elsewhere, had never been successfully achieved), and for fabricating rhenium structures with an integral internal iridium layer in the complicated geometric forms required of rocket engines, using chemical vapor deposition (CVD).

Several 5-pound thrust chambers (potential satellite control units) were fabricated and test fired. The tests demonstrated that the rhenium/iridium structure possesses sufficient strength at 4000° F and is capable of operating at 3800-4000° F for at least 15 hours of burn time, and confirmed the viability of this fabrication method for producing aerospace-grade hardware.

The potential gains from this technology are enormous. Satellite lifespans can be increased by 20%, and the resultant cost savings per satellite have been estimated at tens of millions of dollars. Spacecraft payload capability can be increased by 30%, or conversely, satellite weight can be decreased by several thousand pounds. Scaling up the process for larger engines with similar performance improvements is clearly possible. Work is proceeding with a number of propulsion system manufacturers, satellite manufacturers, the Air Force, and NASA to capitalize on this technology breakthrough.

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Ceramic/Ceramic Non-Degrading Insulators

The results for the Phase I effort indicated that carbon phenolic materials are extremely sensitive to heating rate variations. A significant loss of stiffness occurs during heating which causes carbon phenolic composites to be extremely unstable.

Alternate materials with increased thermal stability coupled with non outgassing characteristics and higher temperature capabilities have been under development. These materials, ceramic/ceramic composites, have been utilized in production programs for both electromagnetic transmission and insulation. Typical material requirements for solid rocket motor (SRM) insulation include thermal stability, low thermal conductivity, minimal outgassing under rapid heating to prevent pyrolysis gas build up sealed sections, retention of properties at elevated temperatures and acceptable erosion rates where the insulator is exposed to propellant combustion.

The objective of the Phase II effort is to fabricate and evaluate advanced ceramic/ceramic composites as substitutes or replacements of reinforced organic matrix (carbon phenolic, silica phenolic) insulation for SRM nozzle applications.

COMPANY: Fiber Materials, Inc.
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■ SPACE & MISSILES

Thermionic Converter Technology for Multimegawatt Space Burst Power

Nuclear reactors are leading candidates for space missions under consideration which will require multimegawatt power for durations ranging from hundreds of seconds to months. In-core thermionic energy conversion offers the possibility of very high power-to-mass ratios for such systems. The initial technology base for thermionic converters operating in a high-power, very high emitter temperature mode (> 2400 K) was established by experimental work in the USSR during the period of 1973-1983.

The Phase I SBIR study indicated that the familiar metal-emitter cesium-vapor converter would have equal or better performance compared to either the carbide emitter or barium additive converters which were the subjects of the USSR work. The Phase II study· 1) provides a technology base for thermionic converters with metal emitters operating in the very high temperature range, 2) experimentally maps the performance of pre-prototype electrically-heated converters, 3) estimates the performance of nuclear space power systems which use such converters, and 4) initiates the groundwork for fission-heated converter tests in Phase III.

Experiments presently planned or under construction include tests of two cylindrical converters. The first test maps converter performance with a tungsten emitter in the temperature range 2200 to 2800 K. The second uses a tungsten-clad emitter containing depleted uranium dioxide tungsten cermet "fuel". This will give valuable information concerning fuel-emitter interaction and its effect on performance. Experiments in progress at Arizona State University are examining the properties of tungsten-osmium alloys and chemically vapor deposited rhenium as emitter surface materials. Such "high bare work function" materials could ease converter design requirements and increase lifetime by enabling wider interelectrode spacings. A system analysis task is also underway, examining burst and alert mode nuclear system performance and extending work done in Phase I.

COMPANY: Rasor Associates, Inc.
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Liquid Barrier Coatings for Air Force Rockets

The Air Force is confronted with two problems that hamper accurate deployment of air-launched rockets; namely, corrosion of exterior surfaces and migration of moisture and/or liquid organic ingredients in solid rocket motors.

These motors consist of a case, insulation to prevent excessive heat build-up of the case during ignition, a barrier film and solid propellent. The sensitive materials are motor cases containing steel or epoxy composites and the propellent. The case is sensitive to moisture, especially in marine environments, and may become weakened or lose accuracy of control as a result of corrosion product build up on control surfaces. Within the case, migration of plasticizer or curing agent from the propellent or the migration of moisture into the propellent may adversely affect accuracy during ignition. Therefore, liquid barrier coatings are sought to be applied either to exterior surfaces to prevent corrosion or within the case to prevent migration of moisture, plasticizer or curing agent.

Initially, the coatings industry was contacted and the literature was searched to determine what coatings were available or could be formulated to meet the Air Force requirements. These included excellent adhesion to all motor case surfaces and resistance to weathering and corrosion or to migration of moisture, plasticizers and curing agents.

During this project, a total of 54 commercial coatings (24 primers and 30 topcoats) have been evaluated and 76 coatings (31 primers and 45 topcoats) have been formulated and evaluated. The project is approaching completion and it is anticipated that about 16 commercial or formulated coating systems (primer plus topcoat) will meet Air Force requirements for use either as anti corrosion or barrier coatings, or both, on both steel and composite substrates. Plant production samples of the final candidate coating systems will be submitted to the Air Force for field evaluation.

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GaAsP Top Solar Cells for Increased Solar Conversion Efficiency

The development of multijunction solar cells is the key to achieving large increases in solar power conversion efficiency over current state-of-the art technology. In the optimal multijunction design, the top solar-cell is the most critical since, by itself, it generates two-thirds of the total power generated by the solar cell stack. There are two viable technical approaches for the top solar cell for the mechanically-stacked tandem solar cell. GaAsP/GaP and AlGaAs/AlGaAs. Both top solar cell approaches have demonstrated good device properties. No other approach has made acceptable devices. The principal advantage of GaAsP/GaP is in its rugged, transparent mechanical substrate (GaP), the disadvantage of GaAsP lies in the lattice mismatch between the substrate and the active GaAsP device layer.

GaAsP/GaP top solar cells have been prepared with the highest practical transparency and solar cell performance characteristics. The results achieved during this program are in the following table of parameters.

	TARGET	ACTUAL
Transparency, < Eg (%)	95	
Voc (volts)	1.46	1.43
Jsc (mA/cm2)	14.9	14.5 (1.95eV)
		19.8 (1.78eV)
FF	.84	.84
AMO Efficiency (%)	13.5	10.6

AstroPower has achieved top solar cell efficiencies of over 10% with both GaAsP and AlGaAs materials. To put this in perspective, 13.5% is required for 4 terminal; 2 junction efficiency of 25% with state of the art silicon bottom solar cells. Also lattice matched AlGaAs top solar cells on 100 micron transparent AlGaAs substrates have been prepared with 11.2% overall conversion efficiency. These results lead to immediate benefits for the Air Force in terms of overall conversion efficiency, array size and power density, radiation survivability, and manufacturability.

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Transpiration Cooled Nose Tip Technology

Discrete injection transpiration cooled nose tips have the potential of being employed for reentry vehicle cooling. The attractiveness of this type of active cooling technique is that the vehicle nose tip does not undergo any shape changes that modify its aerodynamic performance. A difficulty of discrete injection Transpiration Cooled Nose Tips (TCNT) is that it is not possible to perform ground testing that simulates the flight environment to a high enough degree so that a given design can be qualified for the flight environment that it will experience. Thus the probability of successful flight testing and eventual deployment has a certain amount of inherent risk. In addition, for a successful design configuration, it is possible that the overall TCNT system has not been optimized with respect to weight and/or volume. For these reasons it is desirable to have an appropriate analytical design procedure that can be employed to arrive at a high confidence, high performance system.

A three layer theoretical model for discrete liquid injection Transpiration Cooled Nose Tip (TCNT) cooling is being developed. The overall TCNT theoretical model consists of an outer inviscid layer, an intermediate gas boundary layer and a wall region liquid layer. Each region is coupled through interfacial boundary conditions. The multi layer theoretical model is implemented in a Fortran computer code for application to reentry vehicle nose tip cooling. The model is correlated with experimental ground test data to verify the predictive capability and accuracy of the approach. The current work permits the design of optimum actively cooled nose tip components capable of surviving the reentry environment.

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■ SPACE & MISSILES

High-Efficiency Thin-film Silicon Solar Cells for Improved Radiation Resistance

Radiation damage is the primary performance degradation mechanism of silicon solar cells that are used as energy converters in space power systems. This power loss over time is due to the gradual reduction of the silicon minority carrier diffusion length that results from radiation damage to the crystal lattice. This project is concerned with the design, fabrication, and testing of a new class of thin-film silicon solar cells whose performance is effectively insensitive to diffusion length. Due to this characteristic, these new solar cells must have both excellent energy conversion efficiency and high tolerance to radiation damage. They, as a result, have a much longer useful lifetime in a high radiation environment than presently-deployed silicon solar cells.

The new silicon solar cell design consists of a thin layer of electrically active crystalline silicon that is deposited on an oxide-overcoated supporting substrate. The insensitivity of the device performance to minority carrier diffusion length is due to the thinness of this film. The oxide interlayer acts as a buried dielectric back surface reflector to enhance the film's light absorbance and to passivate the back surface of the film. Using this approach, a thin layer of silicon may be given optical and electronic characteristics that are equivalent to those typically seen only with much thicker layers. The silicon film is grown using a technique called selective liquid phase epitaxy, a material growth process that is capable of rapidly producing large areas of semiconductor-quality material using very simple and inexpensive equipment

The primary result of this work is the development of a silicon solar cell that combines high energy conversion efficiency with radiation tolerance. In addition, this particular design could be used to realize very low cost terrestrial solar cells since the requirement for high-quality, and therefore expensive, silicon is eliminated with this approach. Development of the buried dielectric back surface reflector technology is applicable to all silicon solar cells and optical sensors. Development of the technology for growing crystalline films of silicon on oxide, and selective epitaxy, is potentially applicable to 3-dimensional integrated circuits, to large area flat panel displays, and to high gain thin film transistors.

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Fixed Abrasive Slicing Technique (FAST): A Technique for Producing Lower Cost Solar Cells for Spacecraft Applications

Single crystal gallium arsenide (GaAs) substrates are required for producing high efficiency radiation resistant solar cells for space. Currently these substrates are produced by slicing expensive GaAs crystals so that only 32 substrates are obtained per linear inch of crystal. The surface damage introduced by the slicing operation is deep and has to be removed by polishing prior to solar cell fabrication.

This program was initiated to continue development of a multiwire slicing technique, the Fixed Abrasive Slicing Technique (FAST), to improve material utilization by slicing twice as many substrates per inch and with lower surface damage. A sensitive crystal feed mechanism was designed and built, and improvements in process variables were accomplished. The FAST machine was modified to include computer control of the variables during slicing and data logging. It was demonstrated that 6-i substrates per linear inch with 100% yield were obtained with a surface damage depth of less than one-half that obtained for commercially available substrates.

Benefits to the Air Force and industry are an increase of 50% in material utilization of expensive crystals and reduced subsurface damage, which will reduce cell processing costs and increase yields. Additionally, this technology is ideally suited for slicing other expensive crystals such as new generation germanium solar cell materials for digital integrated circuits and electro-optical devices.

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Optical Target Detection

The project goal is to make an object recognition program, developed in Phase I, work from real line images, as opposed to simulated lines, and perform in less than a second on a personal computer. An object recognition program is part of a computer vision system. Various modules and steps in processing from an input image to object position information must take place. In Phase I the line images were simulated. In Phase II the line images are detected from real video input. Phase II test results show that the object recognition program can detect and localize at least simple objects from a real line image. Test results from Phase I showed that the program can recognize objects in partial view and with interference from clutter.Within each test frame the right and smaller image is the input line image The left and larger image is the input with a solution superimposed.

Further Phase II efforts are directed at improving the speed and capability of the object recognition program. To support this effort, much work has been done to increase the capability of edge, line and curve detector programs. At the end of Phase II, we hope to have sub second recognition time from a line image. Application will not be possible until line detection is equally fast. Sub second line detection through the use of nueral networks is possible within a few years, but is beyond the scope of this Phase II.

A computer vision system capable of object recognition in less than a second would have many applications in defense and industry. Vision-aided missiles would be able to hit enemy aircraft while avoiding our own. Cruise missiles, with non-nuclear warheads, would be able to hit with enough precision to disable power plants, refineries, bridges, etc Thousands of key points in an enemy country would be disabled leading to economic paralysis. The threat of such paralysis should be a convincing *non-nuclear* deterrent.

COMPANY: Computer Algorithm
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Integrated Process for LOB Correlation and Classification of Battlefield Targets

A prototype system known as "NODE FINDER" has been developed which uses a unique approach to the disambiguation of information about emitters detected and located via single lines of bearing. Because of the growing number and modulation flexibility of modern combat emitters, detection by single line of bearing techniques frequently produces multiple target candidates along the same line of bearing. NODE FINDER employs a robust composite of techniques to determine the correct specific emitter classification and location. The system accepts conventional sensor reports as input and translates them into clusters of target information. The clusters are then examined by three different processes: textual analysis; parametric analysis, and specific emitter identification analysis. Each of these processes produces a further refinement or disambiguation of the information about the emitters in each cluster This evidence is combined to assign composite probabilities to the identification of emitter attributes. The evidence associated with the nodes is now submitted to a process of Function-Space Time assessment, where each node is considered in context with plausible relatives, activities and locations for the time of interest. Finally, the composite evidence from the process is used to suggest a node identification and location.

The system is being considered for its contribution to the problem of single line of bearing information processing and analysis. It is also being considered for its application to a variety of problems where there is a high degree of disambiguation necessary in the analysis of other complex military targets.

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■ GEOPHYSICS

Development of a Pulsed 1.06-Micron Solid-State Coherent Laser Radar for Wind Velocity and Aerosol Backscatter Measurements

Compact and operational wind measuring laser radar (lidar) systems are needed for many uses, such as airline wind shear detection and global wind profiling. The feasibility of developing a pulsed 1.06 micron solid state coherent lidar system for wind velocity and aerosol backscatter measurement was established during the Phase I effort. It is now possible to stabilize a Nd:YAG laser and make coherent observations. The rapidly developing solid state laser technology has several promising advantages over CO_2 laser technology, including efficiency, compactness, long lifetime, less expensive optical materials, the availability of optical isolators, and the absence of consumables.

Operation at eyesafe wavelengths and total diode laser pumping now appear feasible. We have developed a coherent lidar system utilizing solid state Nd:YAG lasers operating at 1.064 microns, which is designed for measurements of atmospheric wind velocity and aerosol backscatter. The lidar output is 10 mJ/pulse with a 20 cm diameter telescope. The output energy is obtained by operating in a master oscillator power amplifier (MOPA) configuration. The heterodyne signal is detected and processed by an I,Q complex receiver. A LeCroy 9400 digital oscilloscope and a DRC MicroVAX II computer are used to provide the FFT derived target velocity. Doppler velocity measurements have been made from standard moving targets such as belt sanders and discs. Atmospheric measurements are currently in progress.

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Hardened Remote Digital Data Acquisition System

High explosive induced ground shock and airblast are used to simulate the effects of a nuclear detonation on geological media and structures. Current measurement systems which employ long (4,000 6,000 ft) hard wire connections between transducers and data acquisition systems making cable length are a limiting factor in acquiring high frequency data. This project has succeeded in designing and developing an eight channel digital data acquisition system, hardened to 20,000 g's and 14,500 psi, which can be buried just outside the crater region of a high explosive test. The system is microprocessor controlled with all analog and digital parameters programmable from a terminal in a control trailer. The unit has rechargeable battery back up power with the capability to record data for two minutes after external power is lost and retain the data in memory for one week to allow excavation and recovery of the system.

The data acquisition system features a high impedance differential input, programmable amplifier gain from 1 to 800, programmable anti aliasing filter with a range from 5 kHz to 100 kHz, programmable excitation from 0 to 12 VDC, programmable or automatic offset control to +/- 10V, and a programmable, variable, sample rate from 2 us to 125 ms in 1 us increments with 12 bit resolution. Each channel can store 122,880 data points, and the programmable parameters mentioned above can be changed at each 4096 point memory partition. The system can be triggered with an external input, at a pre-set time or by data from the test event.

The Hardened Remote Digital Data Acquisition System reduces the number of long electrical lines from the explosive test bed to the instrumentation recording trailers to eight to one and cuts the number of required trailers by two thirds. The frequency response of the system is more than ten times better than existing analog acquisition systems and provides the capability to acquire data not now obtainable. The embedded processor design of the system allows flexible use of the remote system limited only by the system hardware and system operation by a terminal as well as a computer.

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Reentry Environment Measurement System

Certain atmospheric data gathering missions require operations in either hazardous or remote locations. Many times the location or need for real-time data precludes the presence of manned equipment in the area of interest. Aeromet has developed the Reentry Environment Measurement System (REMs) to gather meteorological data in manned or unmanned operations.

The unmanned data acquisition system (UDAs) is a computer system that resides on board the mission aircraft and can function independently from the ground control system (GCS). The UDAS consists of a Motorola 68020 computer and a write once read many (WORM) mass storage medium using optical laser cartridges. Data is also telemetered to the GCS, allowing real time decisions by ground-based personnel.

In addition to pressure, temperature, and humidity sensors, the REMS includes particle measurement probes. A slow scan video system provides real time snapshots of visual conditions at the remote location. These shapshots are telemetered to the GCS as an aid to ground based personnel. The aircraft launched meteorological sounding system (ALMET) provides pressure, temperature, humidity, and winds, from sea level to 80k ft. The REMS includes the capability to remotely launch ALMETs and telemeter the sounding data to the GCS.

The REMS development program resulted in a data system so advanced beyond previous systems in capability, user interface, and size that it has replaced the previous data collection systems on Aeromets Learjet and is operational for remotely piloted aircraft.

COMPANY: Aeromet, Inc.
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An Electrocatalytic Waste Reactor

The U.S. Air Force expressed a need for the development of a waste disposal system capable of oxidizing organic waste materials in a closed environment. An emphasis on reclaimation of useful by products was desirable.

An electrocatalytic process which oxidizes organic waste materials in aqueous media at 100 150 degrees C utilizing an electrochemical catalytic reaction was developed to prototype stage. The oxidation rate of the organic compounds is further increased by the use of a homogenous co catalyst. The product of the organic oxidation is principally carbon dioxide (CO_2) with small amounts of impurities whose levels are dependent on the nature of the waste material. The electrocatalyst is regenerated by the anode of an electrochemical cell, wherein hydrogen is produced at the cell cathode.

A prototype Electrocatalytic Waste Reactor (EWR) was then designed, constructed and operated, with the data generated compared with the engineering model. Finally, an unsteady state engineering model was developed for application of an EWR to more realistic load and composition conditions.

Results of the experiments with various model compounds, e.g., cellulose, fat, urea and detergent, demonstrate the application of the process to a broad spectrum of organic waste materials. An engineering model predicts the operating characteristics, size and cost of an electrocatalytic waste reactor, given an average amount of waste to be processed per hour in a steady state mode.

The results of work performed indicate that a variety of organic wastes such as sewage sludge, manure, municipal solid waste, and biological wastes can be effectively oxidized using an EWR. Economic analysis of the process further indicates that the process has a good commercial potential.

EWR as a resource recovery technology offers economic and environmental advantages over other processes via visits capability to produce electrolytic hydrogen and due to the controlled oxidation of waste products using a wet oxidation method.

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■ GEOPHYSICS

Infrared Thermography Analysis and Image Enhancement System

An infrared thermography analysis workstation has been developed which improves and enhances the thermography capabilities of commercially available infrared scanning systems. The workstation consists of a Zenith Z-248 computer (IBM AT compatible), a Matrox image capture and graphics board, and infrared analysis processing software. The infrared analysis processing software is the primary innovation in the infrared analysis workstation. The processing software integrates the capabilities of the infrared scanning camera, the image capture and graphics board, and analysis algorithms to produce detailed and accurate three dimensional thermal images. The workstation software is written in the C language and controls all image capture analysis and processing functions. Any infrared or standard video signal; in the RS-170 format, can be input to the system for analysis or image enhancement.

The three dimensional color thermal plots are displayed onto a color monitor after being selected from a plane view of an infrared image window. After the window is processed, it is possible to generate both horizontal and vertical thermal line plots of any location within the selected window. The thermal information from the infrared scanning camera and presented by the data plots may be corrected for different material emissivities, object shapes (cylindrical or flat surface at angles) and for the observation angle relative to the camera. Included in the software is a large data base of emissivities for most common engineering materials over a wide range of temperatures to facilitate analysis of different materials. It is possible to analyze a thermal image made up of multiple elements (i.e., steel, graphite, ceramic) all within the same infrared window.

This innovative infrared analysis system provides the capability to derive more complete thermal data acquisition coverage and accuracy than is presently available with an infrared scanning system alone. The developed system integrates the non intrusive thermal measurement capabilities of infrared scanning systems with image capture hardware and processing software to obtain a more complete and accurate thermal representation of heated objects. This infrared thermography analysis system is a significant improvement over the present capabilities of infrared scanning cameras and what can be obtained with thermocouples for determining surface thermal measurements and profiles.

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Total Liquid Water Content Meter

Aeromet, Inc. was awarded a Small Business Innovative Research Contract by the U.S. Air Force Ballistic Missile Office to develop an airborne instrument for measuring the water contained in cloud hydrometeors. This effort is necessary because cloud particles can cause considerable erosion damage to the exposed surfaces of reentry vehicles (RVs). This damage can alter the performance and lead to the loss of the RV. In addition, the general scientific benefit of analyzing water passing through phase changes will lead to a better understanding of the dynamics and life cycles of clouds as well as the distribution of water in the atmosphere. The Aeromet developed instrument for accomplishing this analysis has been designated the Total Liquid Water Content Meter (TLWCM).

The TLWCM employs the principle of differential water vapor measurement in which a sample stripped of all hydrometeors is compared to a sample in which all hydrometeors have been vaporized. The instrument uses two basic autonomous circuits operating simultaneously. One circuit is dedicated to processing the particle laden sample, it heats the sample to a level that ensures total vaporization. The vaporized sample is then measured using a high response hygrometer. The other circuit separates the hydrometeors from the cloud sample and measures the water vapor content on an identical separate hygrometer. The separate sample and ambient vapor measurements from each circuit are then integrated by a computer for the calculation of the total net liquid water content. This combined data is then logged to the data acquisition system. Aeromet employs two unique new features in the TLWCM. The differential water vapor content measurement for computation is based on actual measurements and iso kinetic flow control for accuracy by ensuring volumetrically representative and sample synchronous water content measurement.

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A Multispectral Cloud Property Sensor for DMSP

The Phase II program exploits the simulation/retrieval capabilities developed and demonstrated in Phase I We applied these tools to define a multispectral cloud property sensor for DMSP. The simulation modeling capability is used to identify appropriate spectral regions to obtain desired information on specified cloud properties. The retrieval capability is employed to optimize channel selection and assess the quality (i.e., accuracy) of the resultant cloud property determinations. These calculations are exercised for a variety of realistic earth background, atmospheric profile, cloud property, and sensor geometry scenarios. The study is supported by actual data samples from existing multispectral imagers for technique development verification and validation. Data analysis and cloud property retrieval from the multispectral cloud property sensor are integrated with potentially useful data from other DMSP sensors primarily those of the suite of microwave instruments including the SSM/I imager, the SSM/T temperature profiler, and the SSM/T 2 moisture sounder.

The retrieved cloud parameters are of potential utility to operational nephanalyses, to numerical weather prediction and optical propagation models and to building a high quality cloud climatology. The cloud parameter retrieval methods developed are potentially useful for other imaging systems, such as Landsat and AVHRR. Cloud data will also support editing and quality control for sounding sensors potentially affected by cloud such as the millimeter wave moisture sounder (SSM/T-2).

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Mosaic Infrared Scene Simulator

The Air Force has a strong interest in the use of infrared imaging systems for strategic defense. The infrared package sensor would be satellite based. The imaging sensors would be observing the "Above the Horizon" zone while avoiding the obvious hot objects like the sun, earth and moon. The targets one would hope to detect would be satellites, missile busses, reentry vehicles and decoys. When in free flight, only the target surface emission of earthshine reflection can be observed. The radiation from the target peaks at around 10 microns wavelength in the infrared region (corresponds to a temperature of around 300K or 80°F). Unfortunately, there are two sources of interference in the background infrared emitted from stars and zodiacal light emitted by dust particles within our solar system. One would like to have a facility to realistically test sensor systems on the ground. Simulation of targets and background scenes is necessary in order to satisfy this requirement.

Background scene simulation calls for 4 quantities to be controlled. star intensity, star density, zodiacal light intensity, and zodiacal light pattern control. The detectable star intensity varies by a factor of 100. The observable star density can vary from 1 to 100 stars square degree depending upon field of view. The zodiacal light can vary in intensity by a factor of 2. The zodiacal light occurs in the form of diffuse striations against the dark sky. Realistic scene simulators must incorporate these factors into the scene.

Our simulator allows for control of all the above quantities. Our Mosaic Infrared Scene Simulator utilizes custom patterned diffraction gratings to form infrared images containing stars and zodiacal light patterns as required Modulation of the diffraction efficiency over the surface of the grating allows control of the amount of infrared radiation which is diffracted and then forms the desired image. The use of a diffraction grating eliminates extraneous light which would otherwise interfere with the simulation. The light pattern which is diffracted off the grating is then imaged onto a diffuser screen for the imaging system to observe. Star densities of 1, 10, and 100 stars square degree and brightness varying by a factor of 100 will be provided. Zodiacal light intensity can vary by a factor of 2 and be patterned and sinusoidal intensity bands of 3, 10, and 30 cycles across the grating. This system will be integrated into the Arnold Engineering Development Center (AEDC) Tullahoma, Tennessee low temperature infrared simulation facility. This facility provides the necesary cold environment for testing infrared optical systems on the ground. Our simulator will allow evaluation and comparison of various infrared imaging systems being studied by the Air Force.

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■ GEOPHYSICS

Phased Array Imaging in Partially Coherent Light

Long range target tracking missions are increasingly characterized by extreme acquisition and tracking requirements that demand systems which return images with high spatial resolution and signal to noise ratios. Tracking system analysts are investigating phased array optics as a means to achieve increased aperture size and consequently better images and greater tracking precision. While theoretical models exist for phased array systems in noncoherent and fully coherent light, the actual target return in an active tracking situation would be intermediate, partially coherent light, for which no accurate model exists.

The problem of phased array imaging in partially coherent light is further complicated because partial coherence does not produce noise in the classical sense, but superimposes unwanted and highly unpredictable spatial modulation.

Therefore, the objective of this Phase I work was to develop a theoretical model for partially coherent light useful for the design of a pupil plane transmission screen, such that when light from a given source is transmitted through the screen the power collected in a given object circle is optimum.

The approach to solving this problem led to the development of a mathematically rigorous formalism for maximizing the concentration of energy in a specified image or object circle. By optimizing the absolute encircled energy, an improvement in pupil function was achieved, which is the standard measure of beam quality for laser devices and beam control systems.

The results of this effort can be used in future target signature characterization studies and speckle noise reduction studies to produce new algorithms for minimizing the effect of partial coherence.

While the problem examined was specific to long range active tracking applications, the technique employed can be extended to many applications, including laser communications technologies, laser based remote sensing studies, commercial camera design, and medical imaging and automatic inspection systems.

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The Development of Shear Wave Technology to Assess Geotechnical Conditions

Subsurface studies for important underground installations conducted by means of conventional drilling and sampling programs can be time consuming, expensive, and can miss important geologic information if the boreholes are not properly positioned. Shear (S) wave measurements offer the potential to characterize geotechnical conditions beyond what can be achieved with conventional technology. As a demonstration of this, a field experiment was conducted in Chavez County, New Mexico with the goal of characterizing rock properties to a depth of 4,000 feet. Innovative S wave seismic survey systems were used to gather the basic data for interpreting the structure, lithology, and rock properties of the subsurface. The geotechnical model thus developed compared favorably to conditions known from comprehensive well control. This research opens the possibility for improving the resolution and cost effectiveness of geotechnical surveys where numerous, expensive boreholes may not be an appropriate exploration strategy.

The research also evaluated the application of ring laser gyroscope (RLG) technology to the recording of S waves. As an RLG is sensitive only to rotational components of motion, it is ideally suited to enhance the detection of S waves as a component of a ground motion sensor (geophone). Specifications for a ring laser geophone have been prepared and are awaiting application towards a prototype system. In addition to geotechnical surveys, such a system could have many other applications, such as the measurement of the torsion of buildings under earthquake or wind loads, phenomena not yet well measured or fully understood.

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CONTACT: William J. Johnson

HCl Monitor

At present, the short and long term environmental impacts of massive HCl releases due to Space Shuttle and other solid propellant rocket launches are not well characterized. It is important to measure the atmospheric HCl content in both the vapor and aerosol forms. Spectral Sciences, Inc. (SSI) has developed a combination vapor aerosol HCl monitor under Phase II SBIR (Small Business Innovative Research program) funding from the Air Force Engineering Services Center (AFESC), Tyndall AFB, Florida.

The instrument consists of four major components. (1) an air sampling optical measurement unit, (2) a power supply and analog signal output unit, (3) an analog to digital (a/d) converter and timing pulse unit and (4) a personal computer (PC). An air sample is drawn through the aerosol evaporator which vaporizes the aerosols and releases the dissolved HCl into the gas phase. By turning the aerosol heater on and off, one can determine both the total HCl (aerosol and vapor) and the vapor phase HCl. Data acquisition and analysis are controlled by a remotely located PC. A 1000 ft signal cable allows the PC to be located in a bunker or control room and enables real time monitoring of the concentration measurement.

The device is based on measuring the infrared absorption of gas phase HCl in the 8.4 um wavelength region. The measurement approach differs from other infrared devices in that it utilizes a novel infrared light source. In essence, the source consists of HCl in a heated cell which emits the characteristic HCl line spectrum. The primary advantage of using a light source which is spectrally matched to the absorption spectrum is one of species selectively. This enables quantitative measurement of very small species concentrations in the presence of strongly absorbing species whose absorption line positions are spectrally uncorrelated with the source line emission. The dynamic range of the HCl monitor is 0.1-10^3 ppm.

COMPANY: Spectral Sciences, Inc.
PHONE: (617) 273-4770
CONTACT: Dr. Lawrence S. Bernstein

Implementation of an Ionospheric-Image File Management, Processing and Display System

Research in ionospheric physics conducted by the Air Force and other institutions involves the collection of large quantities of image data. Perhaps most voluminous are the All Sky Imaging Photometer (ASIP) images collected by a network of ground based and airborne systems. These systems record wide angle lens imagery on film, analog videodisc, and in digital form. The ground based system consists of three stations in Greenland and Spitsbergen. It records images continuously at approximately one minute intervals through the polar winter night. The Ionospheric Image Processing System (IIPS) is a workstation developed by Northwest Research Associates, Inc., to support the management, analysis and interpretation of these data.

In hardware terms, IIPS consists of a computer, image processing and graphics board, RGB and monochrome monitors, film recorder, printer, video camera, 35 mm film transport, and optical videodisc recorder. The film transport and videodisc recorder can be controlled by the computer in both interactive and automatic modes. In the latter case, lengthy sequences of film images can be copied to the videodisc medium. Once this is done, the researcher has fast, random access to any of up to 16,000 images on a single disc.

A variety of software has been developed to accomplish various activities on the IIPS workstation. Most important are programs for the geometric restoration of ASIP images. Any image of interest can be digitized from either film or videodisc and processed to remove the projective distortions associated with the ASIP imaging system. Processed images from several stations can be combined in a large scale composite view in arbitrary map coordinates. Another program provides a friendly, interactive environment for manipulating image data. All aspects of the IIPS graphics display are controllable in this environment.

COMPANY: North West Research Associates, Inc.
PHONE: (206) 453-8141
CONTACT: R. David Lucas

■ GEOPHYSICS

Simulated Ground Response Using Non-Linear Elastic Moduli

Soils experience a reduction in strength under strong shaking, such as during earthquakes. To aid in the design of earthquake resistant structures, soils engineers require knowledge of soil properties at different strain levels. Laboratory measurements, which have traditionally been used to accomplish this goal, suffer from problems of sample disturbance.

We present a fast, efficient, field technique which measures shear modulus and damping values in soils insitu over strain levels comparable to those used in laboratory testing. The technique consists of analyzing seismic surface waves, generated by a falling weight and recorded on the surface using closely-spaced velocity-sensitive geophones.

Because only surface sources and receivers are used, the technique can be rapidly deployed and avoids the cost of drilling boreholes. Derived soil properties are representative of the upper 20 30 feet of the soil column, which is where the largest strain levels occur and which is also generally difficult to sample for laboratory determination of dynamic properties. The insitu method can therefore be used on a stand alone basis or as a compliment to other methods used to predict the dynamic earthquake response at a particular site.

COMPANY: Weston Geophysical Corp.
PHONE: (617) 366-9191
CONTACT: Vincent J. Murray

Stratospheric Cryogenic Interferometer Balloon Experiment: Data Reduction, Validation, and Analysis

The Stratospheric CRyogenic Interferometer Balloon Experiment (SCRIBE) is a balloon borne 0.06 cm^{-1} resolution infrared interferometer spectrometer. SCRIBE was designed by the Air Force Geophysics Lab (AFGL) to demonstrate the feasibility of making high resolution measurements of atmospheric emission in the stratosphere. This experiment provides the Air Force with measurements of the background atmospheric radiance against which its optical systems must operate. These measurements are also used to validate models of atmospheric radiance used to predict and evaluate the performance of electro optical systems. Finally, they are used by the scientific community to detect the presence and abundance of trace gases in the atmosphere which are important to the Greenhouse Effect and to the ozone depletion problem.

SCRIBE has flown successfully three times since 1983 and has generated a large volume of data. However, the task of reducing and analyzing the data was scattered among several different contractors while AFGL had no local capability to process the data In Phase I, OptiMetrics performed a critical evaluation of the existing calibrated spectra, focusing on verifying the absolute radiometric calibration. Numerous spectra were rejected based upon self inconsistencies and inconsistencies with supporting measurements and model calculations. A set of validated spectra were identified which are available for further analysis. In addition, all the supporting measurements (including atmospheric profiles and flight track) were collected, verified, and published.

In Phase II, OptiMetrics developed the software capability for AFGL to process the SCRIBE data. The software extracts and calibrates the interferograms and housekeeping data from the raw data tapes, calibrates and archives the housekeeping data, and processes the interferograms into calibrated spectra. This system has been applied to the data from the latest SCRIBE flight from which high quality spectra have been obtained. The system is currently being refined in preparation for data from the next SCRIBE flight.

COMPANY: OptiMetrics, Inc.
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CONTACT: William O. Gallery

Development of Aeromet "Clearsky" Three-Dimensional Hierarchial Real-Time Cloud Modeling System

Trends in Ballistic Missile Office tests are toward more stringent weather criteria for evaluation of vehicle performance, optical data requirements, and radar imaging of targets. While satellite imagery and conventional observations allow for qualitative forecasts, test requirements often demand more exact predictions. Three-dimensional modeling can overcome many of those limitations and provide accurate forecasts with the required detail.

The modeling system being developed is composed of several different numerical weather prediction models. In Phase I, Aeromet demonstrated that the cloud model component of the system can be a valuable tool for support of reentry tests. The Convective Environment Local Simulation System (CELSS) cloud model is the heart of the CLEARSKY modeling system. A study was performed to determine the quality of CELSS model forecasts and to determine whether CELSS is suitable for supporting reentry tests.

Cloud model forecast fields for a Trident missile test were evaluated in comparison to manual subjective forecasts, advective model forecasts, and the actual cloud conditions observed by an instrumented Learjet. The observed cloud conditions were relatively well represented by the cloud model forecasts, those forecasts were more detailed and more accurate than manual or advective forecasts. Improvement over cloud model forecasts alone can be achieved by coupling the cloud model to a mesoscale model that, in turn, is coupled to a global model. The CLEARSKY system combines three models in that manner to offset the limitations of any single model.

A Phase II program develops an operational version of the CLEARSKY modeling system. The modeling system is used to provide operational weather forecasting support, on an experimental basis, to selected BMO tests. A routine program is implemented to test and evaluate the modeling system. Quantitative and situational improvements to the modeling system are based on the tests performed. A user friendly interface for the modeling system shall exist, and documentation for the system is available.

The Phase II program is designed to produce the very first three dimensional cloud modeling system suitable for use as an operational forecast tool. The CLEARSKY system provides the test director, with quantified forecasts for environmental severity index, liquid water content, radar reflectivity, attenuation, and other values up to 48 hours in advance of the scheduled launch time.

COMPANY: Aeromet, Inc.
PHONE: (918) 299-2621
CONTACT: Mark L. Bradford

All Solid State Integrating Dosimeter

The objective of this research program is to develop a compact active dosimetry instrument for high altitude flight or low earth orbit use. At the altitudes of interest, approximately 100 km to 500 km, measurable doses can arise from a broad range of radiation types. The new dosimetry system is sensitive to gamma rays, betas, protons and neutrons and reports the dose from each of these types of radiation in real time.

The dosimeter is a compact, self contained, microprocessor controlled instrument that uses all solid state detectors. The microprocessor acquires the data and performs the analysis required to output the dose from each radiation type in rads tissue. It stores the dose data in a chronological format, and provides an alarm capability for doses in excess of a selected threshold. A standard serial communications port is provided so that the instrument can communicate with other computers for purposes such as further data analysis or telemetry.

A prototype of this dosimetry system is being designed and fabricated for calibration and performance studies. This prototype instrument will be available for delivery to the Air Force at the conclusion of the Phase II program.

COMPANY: Radiation Monitoring Devices, Inc.
PHONE: (617) 926-1167
CONTACT: Dr. Gerald Entine

■ ADVANCED WEAPONS

Development of Laser Quality Silver Gallium Diselenide ($AgGaSe_2$)

$AgGaSe_2$ crystals have properties that make them useful in high powered tunable infra-red laser applications. Crystals of sufficient size and optical clarity have been grown to satisfy user requirements for minimum internal absorption and surface damage.

The crystals are grown from high temperature melts onto $AgGaSe_2$ seeds in a two-temperature zone furnace (seeded vertical Bridgman method). Post growth high-temperature annealing reduces internal scattering and absorption. This process is required to produce optically acceptable material. The Phase II program goals are improved process yields, increased crystal sizes, and further improvements in crystal quality.

A broad range of non-linear three wave mixing applications exist for $AgGaSe_2$ crystals. These include their use for second harmonic sum and difference frequency generation, and as an optical parametric oscillator (OPO). An $AgGaSe_2$ OPO could yield broadly tunable, high-average power, infra-red laser radiation for high-speed spectroscopy, photochemistry, optical communication, material processing, remote gas analysis, and wavelength-selective surgery.

COMPANY: Cleveland Crystals, Inc.
PHONE: (216) 486-6100
CONTACT: Jack Hietanen

Laser-Induced Surface Chemical Epitaxy

The goals of this research program are to demonstrate the feasibility of a new laser-assisted deposition technique for epitaxial II-VI thin films and to provide an understanding of the underlying surface chemistry. Termed laser-induced surface chemical epitaxy, this technique is a layer by-layer growth process which uses photons provided by an excimer laser to dissociate adspecies produced by the adsorption of organometallic molecules under ultrahigh vacuum conditions.

Phase I experiments provided initial insight into the thermal and photon induced surface chemistry of two organometallic molecules, dimethyl cadmium and dimethyl tellurium, adsorbed on a variety of surfaces including Au, SiO_2, Si(100), and GaAs(100) Using X-ray photoelectron spectrosocopy as an insitu diagnostic for the chemical state of the absorbed and photodissociated adspecies, these studies showed considerable diversity in the thermal surface chemistry of the systems investigated. Physisorption and dissociative chemisorption to yield monomethyl and metal adspecies were observed. In addition to adspecies surface interactions, evidence for strong adspecies-adspecies interactions was also obtained. Irradiation of the physisorbed adspecies with 193 nm UV photons produced single photon photodecomposition and photodesorption. Similar irradiation of the monomethyl adspecies caused only limited photodesorption. Aspects of the thermal chemistry can be understood in terms of a simple change transfer model.

Phase II work expands upon these results through studies of the effects of photon fluence and wavelength and substrate temperature. The experimental facilities have been upgraded to include low energy electron diffraction and to allow processing and characterization of samples at temperatures ranging from 150 K to 1373 K.

The anticipated benefits of LSCE techniques include reduced growth temperatures and contamination levels, precise control of deposit thickness, and the ability to produce abrupt or graded interfaces.

COMPANY: Aerodyne Research, Inc.
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CONTACT: Dr. Charter Stinespring

Numerical Simulation of Liquid Encapsulated Czochralski Growth of Gallium Arsenide Crystal Under an Applied Magnetic Field

Gallium arsenide (GaAs) is a group III.IV semiconductor characterized by a relatively high electron mobility and large energy band gap. These properties make it an ideal candidate for high frequency, high temperature, and radiation resistant device applications. Single crystals of GaAs have been grown most effectively by the Liquid Encapsulated Czochralski (LEC) method. At present, growth handling techniques depend on the experience of the operators and very often trial-and-errors methods are used. This approach is inefficient and expensive.

Numerical simulations of the detailed LEC system can be a cost effective way to design reliable procedures for reproducible automated growth. The main objectives of this program are to. 1) continue development of a robust three dimensional transient numerical algorithm to understand the physics of heat transfer and hydrodynamic characteristics of the LEC system in the presence and absence of a magnetic field, 2) test the effects of detailed growth elements, and 3) provide optimum growth conditions for reproducible automated growth of large diameter, high quality GaAs crystals.

Preliminary results from the Phase I program showed that a magnetic field can reduce the temperature variations in the system and consequently reduce dislocations caused by thermal stresses in the grown crystal. To validate the detailed simulations, geometries and growth conditions from one of the leading U.S. crystal growers are used for numerical simulations. Observable quantities are then compared with the numerical predictions.

The developed numerical algorithm offers a design tool capability to both the crystal grower and the Air Force to design a next generation chamber. The robust algorithm, in conjunction with advanced sensors and electronics offers the potential of a feed back loop control algorithm during the growth process for the current and/or next generation crystal growth.

COMPANY: Scientific Research Associates, Inc.
PHONE: (203) 659-0333
CONTACT: Y.T. Chan and H.L. Grubin

Laser Hardened Material Effects

The objective of this program was to investigate the possibility of the attenuation or partial blockage of a high powered laser beam when illuminating targets protected with ablative surfaces. Attenuation, if important, would be caused by the formation of particles above the surface (resulting from the condensation of cooled ablation products) blocking a portion of the incident beam. Flux levels of interest range from about 2 to 20 kW/cm^2.

In the Phase I study, blockage models were developed based on test data from the Navy/ARPA Chemical Laser. The models were also in agreement with the results from smaller laser facilities. The preliminary conclusion was that attenuation would not be important during infrared spaced based laser (SBL) attacks against ICBMs protected with standard ablation materials. A Phase II effort was conducted to resolve uncertainties in the model, which included further laser tests.

Phase II testing was conducted in the AFWAL Laboratory. The results verified that attenuation was not an important factor. The analytical model also predicted similar results for much higher power lasers such as TRW's Mid IR Advanced Chemical Laser (MIRACL). Results at MIRACL show attenuation occurs only when localized structural failure occurs, which is a different phenomenon than investigated here.

COMPANY: PDA Engineering
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CONTACT: L.S. Groener

■ RESEARCH SCIENCES/Life Sciences

Development of an Improved Neck for Ejection Systems Test Manikins

Test manikins currently used in ejection seat testing were developed to simulate occupant response in automobile crashes. They have greatest biofidelity in forward and lateral impacts, and so are not well suited to ejection seat testing in which impacts occur vertically. In particular, the manikin's head motion is much less than that of a human occupant.

During Phase I of this effort, potential design concepts for improving manikin neck performance were identified. In Phase II, these concepts are being refined and tested. To assure accurate biofidelity, the head and neck response of human volunteers subjected to prior testing at the Naval Biodynamics Laboratories (NBDL) were carefully studied. Based on these data, correct stiffness and damping characteristics for the neck were established. Materials and mechanisms are now being selected to provide a manikin neck which will approximate the motion of a live occupant in vertical impacts. The major change in the new design is that head rotation will be independent of neck rotation, as it is in the human. The overall assembly will also be less stiff to allow greater and more realistic head neck motion. Models of the improved neck will be fabricated and tested to demonstrate this performance.

It is anticipated that the new neck assembly will be usable on both newly manufactured and existing manikins. It will offer improved simulation of human response in ejection seat tests, and will thus aid researchers to identify and eliminate, or at least limit, causes of head and neck trauma. It may also find application in crash testing of automobiles and commercial aircraft.

COMPANY: Simula, Inc.
PHONE: (602) 893-7533
CONTACT: R.E. Zimmerman

■ RESEARCH SCIENCES/Mathematical & Informational Sciences

Adaptive Computational Methods for Chemically Reactive, Radiative Flows

The simulation of chemically reacting, radiative flows in arbitrary complex computational domains presents one of the most challenging and difficult problems in computational fluid dynamics today. This class of problems in general couples a multiphase viscous fluid flow analysis with a system of chemical reaction and radiation effects which provide source terms for the governing equations. Such a coupled system is complicated not only by the complex interactions of shocks and boundary layers present in the flow domain, but also by the large differences in time scales between the rate at which the radiation and chemical reactions take place and the rate at which the primitive variables in the fluid evolve (ie. density, pressure, velocity, etc.).

Computational Mechanics is in the process of developing computational methods and computer software capable of resolving these complex issues as well as providing an actual estimate of the error in the numerical solution. The approach being pursued incorporates an operator splitting technique (to resolve the time scale difficulties) with adaptive computational methods which dynamically adjust the number of grid points and order of polynomial approximation used in the spatial domain. The adaptive techniques, called h p methods, in general provide the only possible approach for resolving boundary layer and shock interaction effects with a realistic number of degrees of freedom and available computer architecture. Preliminary results indicate that such adaptive methods may reduce the number of unknowns and computer time necessary to provide a given level of accuracy by as much as an order of magnitude.

The adaptive methodology developed here is an extremely powerful technique applicable to solving arbitrary systems of partial differential equations. Thus such methods will not only provide a highly sophisticated analysis technique for solving complex fluid flow problems, but will also provide a reliable, highly accurate analysis made for structural mechanics problems, electro mechanics problems, or any other system of equations, which includes singularities and other solution discontinuities.

COMPANY: Computational Mechanics Company, Inc.
PHONE: (512) 467-0618
CONTACT: Dr. Jon M. Bass

Hypervelocity Vehicle Carbon Nosetip Technology

The objective of this program was to develop improved analytical tools for the design of high performance, carbon-type reentry nosetips. As part of this effort, the conditions under which carbon will melt and the effects of the melting on ablation were investigated. This work included development of a liquid layer melt model for axisymmetric nosetip shapes and experiments in the Arnold Engineering Development Center (AEDC) Track G test facility to evaluate conditions where melting occurs. The experimental results indicate that equilibrium theory is adequate in the melting ablation regime. It was concluded that carbon melting effects are not large enough to be important in terms of nosetip recession.

An updated version of PDA's nosetip recession and shape change program was developed and documented. This computer code, called NOSCREEN, allows for asymmetrical shape change and can include a full six-degree-of-freedom trajectory coupled to the rigid body motion. Thus, the code can be used for bending loads prediction as well as determining nosetip length requirements.

The NOSCREEN code was used to calculate nosetip recession and shape changes for the MK 21 and Impact Technology Program (ITP) vehicles at various circumferential locations (rays) around the nosetips. Trajectory impact point locations and aerodynamic bending loads were predicted based on asymmetric boundary layer transition obtained from flight test data.

COMPANY: PDA Engineering
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CONTACT: Dr. Joseph Wuerer

Large-Scale Turbulence Structuring in High Reynolds Number Flows

Certain electromagnetic radiation signals are seriously affected by aerodynamic and thermal environments associated with ground based optical systems. Losses in intensity and power of the signal results as it propagates through the aperture environment and the turbulent shear flow over it. It has been suggested that improvements in the propagation quality of these shear flows can be achieved by manipulating the flow in a prescribed manner coupled with adaptive correction schemes.

The purpose of this investigation was to generate large-scale turbulent structures in a heated shear flow, to fully characterize the turbulent temperature fluctuations in the flow, and to quantify the optical propagation effects. Experimental simulations were conducted in a low speed wind tunnel using state-of-the-art smoke-wire flow visualization, hot-wire, and holographic interferometry instrumentation to acquire detailed aerodynamic and optical data.

The aerodynamic flow visualization and hot-wire correlation data indicate that large-scale turbulent structures were generated in a repeatable, predictable manner, as a function of the frequency and amplitude of forci g. The power spectral density data indicated that the small-scale turbulent energy can be reduced for certain regions of the shear layer when it is forced in a prescribed manner. These data strongly suggest that the propagation quality of the flow has been improved.

A direct consequence of this improvement will be reduced aberrations through near field turbulence. Also, increased understanding of turbulent fluctuations and associated abberations will be gained and applied to a myriad of systems. Specifically, this knowledge can be applied to any systems that transmit or receive electromagnetic energy at frequencies that are sensitive to density fluctuations in the near field turbulent flow. Candidates for improved system performance include infrared lasers, rangefinders and designators, optical telescopes, lasers, and active and passive sensors.

COMPANY: United International Engineering, Inc.
PHONE: (505) 242-9200
CONTACT: Dr. David C. Chou

■ RESEARCH SCIENCES/Aerospace Sciences

Stress Intensity Factors for Cracking Metal Structures Under Thermal Loading

Analytical and numerical techniques are needed by the Air Force and civilian industries, such as electric power and petrochemical industries, for predicting stress intensity factors of cracked metallic structures subjected to thermal loading. General purpose numerical techniques such as the finite element method are currently available for the solution of such problems. However, they require time consuming modeling of the structural configuration, including the crack, and detailed thermal/stress analysis for each thermal transient to be addressed.

As a result of Phases I and II of this SBIR research project, an interactive, user friendly, personal computer based computer program, AF CRACK, has been generated, which provides accurate solutions and yet shortens the analysis time from days to minutes. This large reduction in analysis time has been accomplished by employing the concepts of Green's functions and influence functions in calculating the stress intensity factors, and by the user friendliness of the resulting software. A total of eight of the most commonly encountered cracked structure configurations, including five two dimensional and three-dimensional models, are included in the AF-CRACK software.

One of the most obvious benefits and applications for the results of this SBIR research is the prevention and understanding of structure failures due to thermal loading, which have been known to cause numerous disastrous structure failures in the past. Since AF CRACK can be made compatible with any existing crack growth algorithms, this computer software can easily be used by the Air Force, aerospace industry, nuclear power industry, and oil and gas industry to analyze crack growth due to thermal loading.

COMPANY: Structural Integrity Associates, Inc.
PHONE: (408) 978-8200
CONTACT: Dr. An-Yu Kuo

Track G Erosion Data Application Analysis

Nosetip erosion performance is a critical factor in all weather reentry system survivability and accuracy. The limited availability of system flight tests requires reliance on ground test facilities to provide necessary nosetip erosion data. AEDC Track G provides the best simulation of key flight parameters and has been used extensively to evaluate candidate nosetip materials. The utilization of the extensive Track G data base, however, has been limited due to (1) Track G facility phenomena which appear to bias the erosion data and (2) apparent differences with flight derived erosion performance.

In order to correctly interpret and apply Track G erosion data to the prediction of materials performance in full scale reentry weather environments, a combined analytical and experimental program was conducted. Results of this program included (1) the quantification of key Track G and flight phenomena through analysis and experiment, (2) the development of an erosion data base for a production nosetip material, (3) the development of phenomenology models to reduce and interpret Track G erosion data, (4) the integration of analysis models into nosetip performance codes, (5) the successful comparison of nosetip erosion performance derived from Track G and flight test data, and (6) the development of recommendations for the utilization of Track G data in flight performance predictions. These results will benefit (1) the development of erosion resistant nosetip materials through more accurate assessment of erosion performance and (2) the evaluation of system effectiveness through the more accurate prediction of the performance of present and advanced all weather flight vehicles.

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An Evaporation-Condensation Smoke Generation System

Aerodynamic testing in large scale wind tunnels requires the production of large quantities of smoke for the purpose of flow visualization. Conventional smoke generators do not have sufficient capacity. In addition, they often require manual adjustment and operator's attention to function properly.

The new evaporation-condensation smoke generation system adopts feed-back control techniques to precisely regulate both the evaporator temperature and the liquid supply. The control functions are integrated by using an industrial programmable controller to gain flexibility. The programmable control system also monitors the local wind tunnel speed and accordingly determines the optimum volumetric production rate of the smoke. With the speed of the smoke jet matching the speed of the air stream, the dispersion of the smoke filaments is minimized and best flow visualization results obtained.

The streamlined design of the smoke generation system is tailored to the open circuit subsonic wind tunnel in AFWAL/SARL, which has a test section of 7x10 feet, a maximum Mach Number of 0.6, and a low turbulence level of 0.02%. The smoke generation system will function under harsh ambient conditions with a minimum amount of attention.

COMPANY: Physical Research, Inc.
PHONE: (213) 378-0056
CONTACT: Chiun Wang

A Pulse Heating Technique for Measuring Carbon Triple Point Properties

The melt temperature of carbon has never been precisely measured in spite of many attempts. The problem is due to the experimental difficulties associated with heating and instrumenting specimens over 4000K. Other carbon triple point properties also remain uncertain for the same reason. These uncertainties have practical implications relative to various defense and commercial applications of carbonaceous materials, particularly those involving thermal protection.

This research developed and demonstrated a new approach for measuring carbon triple point properties. A rapid pulse resistance heating apparatus and a fast response four color pyrometer were used to avoid prior experimental difficulties. A 200 kilojoule capacitor bank, adjustable inductors, and high current switches were assembled to provide current pulses of approximately 50 kiloamp for 1 millisecond and longer. Graphite specimens were contained in an inert gas, high pressure chamber qualified to 6500 psi. A four wavelength, microsecond response pyrometer using a fiberoptic input was fabricated.

Experiments were initially limited with respect to peak temperatures by specimen fracturing prior to completion of energy delivery. Design changes mitigated the fracture problem and several tests were completed for which it is believed that melt or near melt conditions were achieved locally in the graphite specimens. For temperatures above 3000K, pyrometer measurements showed evidence of line of sight obscuration for the slower energy discharge rates. The highest temperature directly measured was 4200K. A carbon melt temperature of 4750K was estimated from energy balance considerations.

COMPANY: Astron Research & Engineering
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CONTACT: Charles Powars

■ RESEARCH SCIENCES/Chemistry & Atmospheric Sciences

Microwave Moisture Sounder Retrieval Optimization

This Phase II research program investigates the alternative application of proposed DMSP microwave moisture sounder (SSM/T 2) data to the inference of water vapor profiles, cloud and precipitation properties, and those of the underlying surface. In the initial (Phase I) effort of this program, simulation models were developed to treat the instrumental response of a sounder operating in the vicinity of 183 GHz to representative variations of cloud and precipitation realistically encountered in the atmosphere. Limited instrument sensitivity and retrieval tests due to the presence of clouds and precipitation have been demonstrated. In order to improve moisture retrievals in the presence of clouds and exploit the demonstrated sensitivity of these millimeter frequencies to obtain cloud and precipitation properties when present, a method is sought which explicitly treats these factors within the retrieval algorithm. The proposed approach will utilize data available from sensors aboard a typical DMSP payload (SSM/T, SSM/I, OLS). Additional tasks are proposed to enhance the simulation model developed under Phase I.

The retrieval method developed will exploit the multispectral sensitivity of the DMSP sensor ensemble to obtain required geophysical parameters which are inaccessible or obtained with degraded accuracy using present approaches. The enhanced simulation model developed under the proposed effort will be generally applicable to assessment of atmospheric effects on millimeter wave systems.

COMPANY: Atmospheric and Environmental Research, Inc.
PHONE: (617) 547-6207
CONTACT: Ronald G. Isaacs

Spectroscopic and Retrieval Studies in Support of Scribe

This research enhances the capabilities to model stratospheric infrared background radiation levels and improve the reliability and accuracy of retrievals of temperature and trace constituents including water vapor from high spectral resolution interferometric data. This work has increased our understanding of the effect of line mixing on the simulation of infrared radiances and on the accuracy of retrieved path characterization parameters.

This research investigated. (a) an enhanced temperature retrieval algorithm for application to SCRIBE data analysis by optimizing channel selection based on the completed sensitivity studies and apply to both nadir and limb scans from 1984 and subsequent data, (b) application of a constituent retrieval capability to obtain estimates of relevant trace gas concentrations to be exercised subsequent to the temperature retrieval algorithm, in particular search for lines of photochemically active molecules with diurnal variation to help understand ozone related photochemistry and diurnal variations of stratospheric transparency, SCRIBE retrieved species concentrations will be compared to those predicted from two dimensional photochemical models and, as appropriate, the NASA satellite data base, and (c) continued and extended our investigation of line mixing and its potential impact on modeling of stratospheric background radiances and accuracy of remote sensing of temperature and trace constituents.

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Intersatellite Image Comparisons

The feasibility of successfully transforming digital data from one imaging sensor (Landsat MSS) to simulate that of another (DMSP OLS) was demonstrated in our Phase I effort. Development of this prototype digital data formatter (DDF) algorithm was based on experience gained in analyzing cloud field characteristics from actual satellite imagery. This unique data set of concurrent satellite images from four operational sensors—Landsat, DMSP, NOAA, and GOES—was acquired during the Phase I effort. In Phase II, we enhanced and augmented the DDF algorithms to treat a broader domain of sensor types and potential cloud analysis regimes, implemented the code of AFGL, both on the Cyber mainframe and as a McIDAS utility, and tested its effectiveness as an interface code between routinely acquired digital imagery data and operational applications models. This effort is supported by the acquisition of additional digital data for development and testing purposes, including planning and requesting a special save of DMSP digital data.

Digital imagery data from satellite-borne multispectral sensors support a variety of meteorological, earth resources, hydrological, and agrometeorological applications models. The digital data transformation algorithms developed in the proposed Phase II effort will enhance the remote sensing of such parameters as cloud, haze, snow, vegetation, and other atmospheric and terrain features of military and commercial interest.

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CONTACT: R. G. Isaacs

Developing a Radiation Tolerant Photodetector

Sometimes it is desirable to measure faint optical signals in the presence of ionizing radiation. This program has developed a novel photodetector which is composed of a special solid state photodetector in a photomultiplier tube, such that the optically generated photocurrents are amplified much more than the radiation induced photocurrents.

Optical photocurrents (signals) are created when the photon generates a photoelectron at the photocathode. Each photoelectron is accelerated to approximately 10 kV before it impinges on the solid state detector. While an optical photon would create one carrier pair in a solid state detector, a 10 kV electron creates approximately 3,000 carrier pairs. The main source of radiation induced photocurrents however, is direct electron excitation by ionization in a solid state detector If the optical efficiency of the photocathode (i.e. electrons per photon) is seven percent, the gain of the tube (carriers per incident photon) is about 210. Thus, in a properly designed tube the optically generated photocurrent (signal) is enhanced much more than the ionization generated photocurrent (noise). Additionally the signal to-noise ratio can be optimized if the solid state detector is only one (10 keV) electron range thick, so that the optical photocurrents (signal) are as big as possible but the ionizing photocurrents are minimized. Finally if a second identical photodetector in the tube is subjected to the same ionizing radiation but shielded from the optical photoelectrons, the ionization induced noise in the blind detector can be subtracted from the signal and noise in the sighted detector. An optimized and miniaturized detector has been developed for laser gyro applications and tested to demonstrate the validity of the preceding arguments.

COMPANY: Jaycor
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CONTACT: Burr C. Passenheim

Microencapsulated Phase Change Materials for Enhanced Heat Transport and Storage in Electronic Systems

An improved means for the thermal management of both electronic and mechanical systems has been developed using microencapsulated phase change materials (PCMs). These micronsized PCM particles can be used either as powders, pastes, fillers, or slurried in a variety of carrier fluids.

The center PCM core of the particles can be selected to melt at a variety of different temperatures. The surrounding shell contains the melted core material and prevents its undesirable mixing with the carrier fluid or contact with other materials. When used passively in a powder or paste, the PCM materials provide significantly enhanced thermal storage for limited weight or volume applications. When the particles are slurried in a circulating carrier fluid, they can provide significantly enhanced active cooling or heating. The carrier fluids can be either aqueous or non-aqueous or even a liquid metal. The core materials have included paraffins and metals, while the encapsulant shells have been of polymers or metals.

When properly operated, the circulating coolant can provide a significantly enhanced thermal capacitance for the fluid as well as enhancement of the heat transfer coefficient between the fluid and its surroundings. The high latent heat of fusion for the PCMs also provides for practically isothermal heat transport and storage.

This program has also included the development of an in line thermal capacitor, a quick-disconnect fluids connector, and a low flowrate slurry flow meter. Applications include electronics or mechanical passive and active systems for enhanced thermal management (heating, cooling, or storage), pourable or molded heat sinks, improved circulating coolants, quick disconnect couplers or mating compact heat exchangers, flow meters and flexible thermal barriers.

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Numerical Simulation of High Speed Heterostructure Bipolar Transistors

Aluminum gallium arsenide (AlGaAs), gallium arsenide (GaAs) Heterostructure bipolar transistors (HBT) have a great promise for high speed applications. Both as discrete devices and in circuits, they have applications in Air Force's avionics, missile and space programs. Fabrication of these structures is currently underway in many laboratories in the U.S. and abroad. At early stages of the development, numerical simulation of the device (based on fundamental concepts) can reduce the number of costly trial runs and serve as a design aid. The objective of this project was to evaluate the suitability and limitations, if any, of the HBT for high speed applications, and to suggest design modifications to meet the specifications called for by the applications.

A physically meaningful two dimensional computer model has been developed for the HBT and used to identify the impact of various design parameters on the high speed potential of the device. The study has provided insight into the operational characteristics of the device and served as a design aid. In addition, a user friendly computer code is being developed for use by Air Force scientific personnel. The code is capable of providing design information through a careful parametric analysis.

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A Superconductor-Insulator-Superconductor (SIS) Mixer Block for Application at 100GHz

SIS mixers, which are thin film devices operated at very low temperature, are the most sensitive mixer devices known. Their performance in receiver applications has been shown to approach the limit set by the quantum nature of radiation. SIS devices are currently in use in radio astronomy.

In spite of their potential, SIS mixers are still confined to laboratory applications, due to the difficulty of fabricating high quality devices and attendant scarcity, and the required cooling to near absolute zero. This project has attempted to rectify these problems through production of a manufacturable SIS mixer device, complete with an efficient cryostat. The prototype unit is compact and easily transportable. This or similar units can address Air Force requirements in secure communications, surveillance and RADAR, either ground based or airborne.

The prototype system is the result of years of process development in superconducting integrated circuits, as well as advanced engineering of the cryogenic system to maximize operating time and minimize size and weight. By modification of certain feature sizes on the superconducting chip, the mixer can be optimized for frequencies from 30 to 600 GHz, and the cooler can support multiple devices for enhanced dynamic range. This prototype demonstrates that the performance advantages of superconducting electronics can be brought into the field to serve Air Force needs.

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Advanced GaAs FET for Low Noise Microwave and Millimeter-Wave MMIC Frequency Sources

GaAs MESFET technology, in spite of its success in a variety of discrete and Monolithic Microwave Integrated Circuits (MMICs), is not satisfactory for oscillator applications due to the observed excessive FM noise compared to Si bipolar transistor and Gunn diode components. Si bipolar transistors and Gunn diodes are, however, not suitable for monolithic integration at microwave frequencies. The higher FM noise of GaAs MESFET oscillators is attributed to the 1/f noise of the GaAs MESFET device itself. Microwave Monolithics Incorporated has developed a proprietary flash annealing technique which substantially reduces the 1/f noise of GaAs FET devices. Unoptimized devices fabricated and characterized in program Phase I already exhibited a 1/f noise corner frequency below 2 MHz—an order of magnitude lower than standard GaAs MESFETs. Improved devices through optimization of materials, device, and fabrication parameters in program Phase II exhibited a 1/f noise corner frequency close to 1 MHz and a f_{max} over 40 GHz. These devices are well suited for X/Ku-Band frequency source applications.

Low noise frequency sources compatible with GaAs MMIC technology are useful for a wide range of microwave and millimeter wave systems applications. With this technology, higher levels of integration can be achieved with the associated benefits of reduced size, weight, enhanced reliability, and reduced costs. Low 1/f noise three terminal active devices are also useful in ultra broadband applications such as distributed amplifiers where the lower frequency limit can approach DC.

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■ RESEARCH SCIENCES/Electronic & Material Sciences

Thermo Technology for Cryocole Puled Conductors

Conventional railguns incur large resistive losses because of the skin effect, that is, the gun current is carried in a thin layer near the surface of the solid copper rails. These losses cause failure by melting of the rail surface if several shots are fired in quick succession. Active cooling allows the conventional guns to be fired at a rate of about one shot in five seconds (0.2 Hz frequency). To overcome these limitations, this project has examined a novel railgun concept with transposed conductor rails. Estimates show that energy losses are reduced by a factor of 1000 by the use of cryogenically cooled high purity aluminum conductors. Furthermore, active cryogenic cooling with liquid hydrogen enables repetition rates from 10 to 100 Hz.

Experimental research was conducted on this project to fill the gap in knowledge about very rapid transient boiling heat transfer from conductors subjected to repeated current pulses. Heat transfer measurements at 0.1 millisecond intervals were made with cryogenic nitrogen coolant (77 K) and stainless steel conductors that were heated by 2-20 millisecond long current pulses repeated at a rate of 5 to 10 Hz. Single conductors were tested to study the physics of the transient heat transfer processes and to develop mathematical models. Detailed measurements on a segment of the prototypical rail geometry (multiple layers of flat transposed conductor braids and cross-flow of coolant) were made.

The project produced original heat transfer data and new models. The data showed significant differences between transient and steady state heat transfer during rapid heatup and during cooldown in the transition boiling regime. New models were developed for these conditions and for the effect of void fraction in two-phase flow. The models enable refined thermal design methods for transposed conductor rails. Based on these models, resistive losses less than 1% of the projectile kinetic energy, projectile kinetic energy of 100 megajoule, and firing frequencies approaching 100 Hz are estimated. The thermal technology developed here has application to other high pulsed power components such as inductors and bus bars.

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Advanced Antenna Window Performance and Requirements Definition Study

Window materials for advanced reentry systems need to meet a severe set of environmental and electromagnetic requirements. Existing materials and design methods are generally deficient, and improvements are needed in the critical areas of ablation performance, structural properties, electrical transmission and bore sight properties. This program investigated ideas on how antenna windows can be improved.

The major Phase I effort involved test and evaluations of antenna window models. This included testing of fused quartz (Dynasil) and three dimensional silica composites (AS3DX) in the Avco/Textron 10 MW arc jet. The test objectives were to obtain ablation and thermal response data for test models inclined at various angles with respect to the turbulent flow of the jet. Post test analysis of the results indicated that the standard values for emissivity, melt viscosity and transmittance are questionable for these materials. A parametric evaluation of these properties were made using an ablation computer code; good correlation was obtained when a modified set of properties was used. Laboratory measurements are required to verify the analytically-derived properties.

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Voltage Measurement Instrument for Gallium Arsenide Integrated Circuits

Lightwave Electronics has built an instrument prototype that allows noninvasive, nonperturbing, high frequency voltage measurements for on-wafer testing of gallium arsenide (GaAs) monolithic microwave integrated circuits (MMICs). An optical probe beam passing through the GaAs IC substrate measures circuit voltages by sensing the polarization rotation of a beam resulting from the electrooptic effect. High speed is achieved by sampling the microwave voltage waveform with very shod laser pulses from a mode-locked laser.

The goals of the project were as follows. 1) Build a prototype instrument based on the electrooptical sampling research system demonstrated at Stanford University, 2) Test actual circuits on the system in collaboration with MMIC manufacturers to verify the usefulness of the measurements and to identify desirable features in a commercial instrument, and 3) Develop improvements to simplify and automate use of the instrument.

The system developed at Lightwave has a time resolution of 2 picoseconds resulting in a bandwidth of greater than 100 Gigahertz, a 100 microvolt sensitivity, and a spatial resolution of better than 10 microns. Automated data acquisition, voltage calibration routines, and specialized control software have been developed. Several MMIC manufacturers have supplied circuits to test with the system. Based on the measurement results, they are planning to work with Lightwave to use the instrument to improve their MMIC designs.

The potential applications and benefits of the instrument are to reduce chip fabrication costs by early in the process discovery of circuit defects by on wafer measurement before expensive additional processing and packaging, to reduce testing costs using the non contact, nonabrasive optical probe that does not degrade with time or damage the IC, and to provide engineers and designers with a diagnostic and debug tool for intra circuit measurements that can help improve microwave circuit modeling, leading to higher performance and better fabrication yield designs.

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Capacitive Energy Storage at Cryogenic Temperatures

This project was designed to investigate the potential advantages of capacitive energy storage at liquid nitrogen temperatures (77 K) where breakdown strengths are larger than at room temperatures. The project exploits the large dielectric constants (~ 7000) of a new class of ceramic feeroelectric materials which can be inexpensively manufactured using state-of-the-art multilayer capacitor technology.

The research has concentrated on the potential breakdown mechanisms and has attempted to increase the breakdown strength of the materials through investigation and control of material properties and processing methods. Energy storage densities as high as 10 Joules/cm^3 have been achieved in sample capacitors. These capacitors offer the potential of inexpensively storing large amounts of energy for on demand use by systems requiring pulsed energy inputs in short times.

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